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Potential of Power Electronics to Improve the Power Quality of Network Grid

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Abstract: This thesis deals with voltage drop characterization of transmission systems by using power electronics circuits supplied from embedded generation.

Many grids connected power electronic systems, such as STATCOMs, UPFCs, and distributed generation system interfaces, used voltage source inverters (VSI) connected to the supply network through a filter. This filter, typically a series inductance acts to reduce the switch harmonics entering the distribution network an alternative filter is an LCL network, which can achieve reduced levels of harmonic distortion at lower switching frequencies and with less inductance, and therefore has potential benefits for higher power application. However, systems incorporating LCL filters require more complex control strategies.

This dissertation proposes a robust strategy for regulating the grid current connected via an LCL filter. The strategy integrates an outer loop grid current regulator with inner capacitor current regulation to stabilize the system. Asynchronous farm PI current regulation strategy is used for the outer grid current control loop.

Linear analysis, simulation and experimental results are used to verify the stability of the control algorithm across a range of operating conditions and finally expressions for "harmonic impedance" of the system are derived to study the effects of supply voltage distortion on the harmonic performance of the system.

Keywords: Voltage, STATCOM, Voltage Source Inverters (VSI), STATCOMs, rms

I. INTRODUCTION

Power electronic converters are now used in many grid-connected applications including STATCOMs, USFCs, and active interfaces for distribution generation systems. These converters are commonly based on a voltage source inverter (VSI) connected to the supply network.

They are operated to achieve the objectives of power flow regulation to power factor optimization by regulating the current into the grid using schemes such as synchronous frame controllers, predictive current deadbeat control, or hysteresis- based strategies. Typically, simple series inductors are used as the filter interface between the VSI and the grid network. However, these filters require high switching frequencies to acceptably attenuate switching harmonics, particularly in weak –grid applications where supply is sensitive to these harmonics.

In contrast, the alternative LCL form of low –pass filter offers the potential for improved harmonic performance at lower switching frequencies, which is a significant advantage in higher-power applications. However, systems in-corporating LCL filters require more complex current control strategies to maintain system stability, and are more susceptible to interference caused by grid voltage harmonic impedance presented to the grid.

Nowadays, more and more power electronics equipment, so–called "sensitive equipment" is used in the industry process to attain high automatic ability. Susceptibility of these end–user devices draws the attention of both end customer and suppliers to the questions of power quality, especially short duration power disturbances, .e g voltage dip, swells and short interruptions, which can bring substantial financial losses to the end customer. Voltage problems are the most common disturbances encountered.

The concept of the custom power devices was introduced some years ago to improve power quality in the industrial plants. Several different custom power devices have been proposed, many of which are based on the voltage source converter (VSC), e.g. dynamic voltage restorer (DVR) and Stack Synchronous Compensator (STATCOM) etc.

With a DVR installed in series or a STATCOM connected in shunt with the critical load, the line voltage can be restored to its nominal value within the response time of a few milliseconds, thus avoiding any power disturbances to the load. The STATCOM has a function of compensating reactive power, absorbing the harmonic and compensating the voltage dip. This thesis focuses on the function of compensating voltage dip.

II. SIMULATION CIRCUIT

A. First Step Steady State

1) First case represents single line diagram before voltage dip. To study effect the power quality on network before voltage dip and also no load in this case have been founded the system is steady state, however well seen the next step after this step.

$P=8.1821\times 10 * 6$ MW

$Q2=2.9978\times 10 * 6$ MVAR

$V=13500$ V

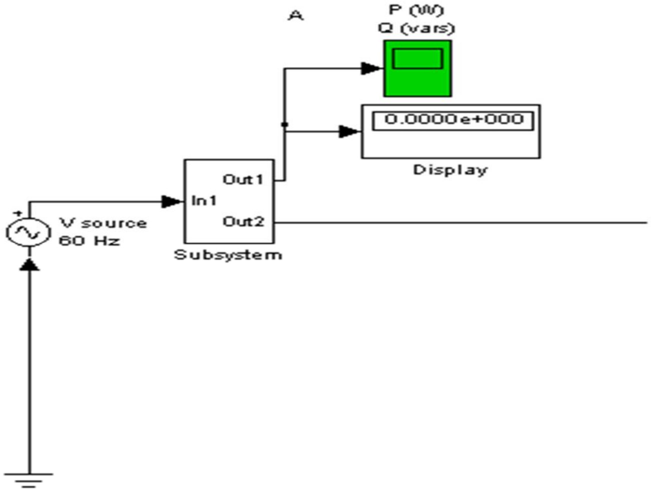

Fig 1: Modelling of simulation at steady state

2) The second case represents single line diagram after voltage dip.

Can see the Impact of voltage dip on power quality, the real reactive power found in this case lower than the first case due to power loss in the transmission line and also large load at the end of system power quality effect due to the voltage changing to improve the power quality in the system what exactly do to improve this the power quality.

$P=6.9663\times 10 * 6$ MW

$Q=2.0899\times 10 * 6$ MVAR

$V=8\times 10 * 3$ KV

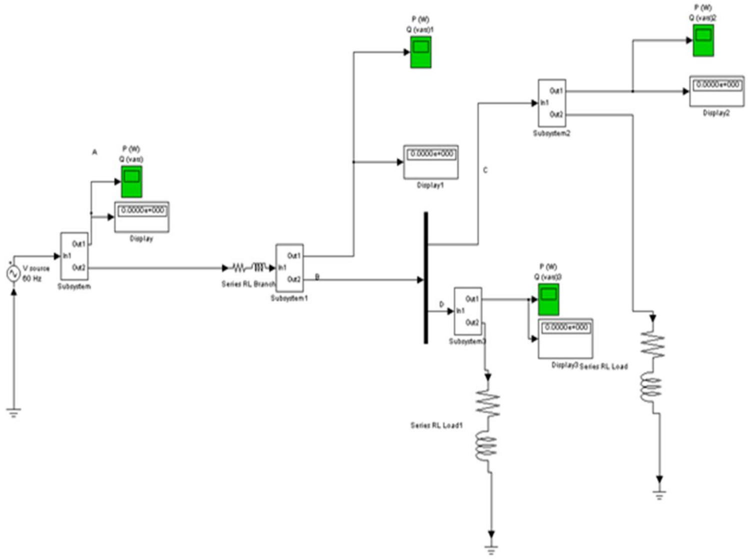

Fig 2: Modelling of simulation at power system

B. Second Step Connect The Embedded Generation With Booster Transformer

1) First case the effect of embedded generation connect with booster transformer before connecting the transmission line or any load in the power system found the real and reactive power sudden increase due to voltage supply but less than the steady-state.

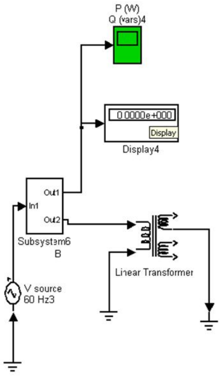

Fig 3: Modelling of simulation at power system connect the (EG) with (BT)

2) The second case in this step connects the transmission line two between booster transformer and bus bar between loads and the first transmission line the booster transformer compensator voltage drop in a transmission line to keep the voltage in the bus bur equal the voltage of embedded generation to keep the system steady.

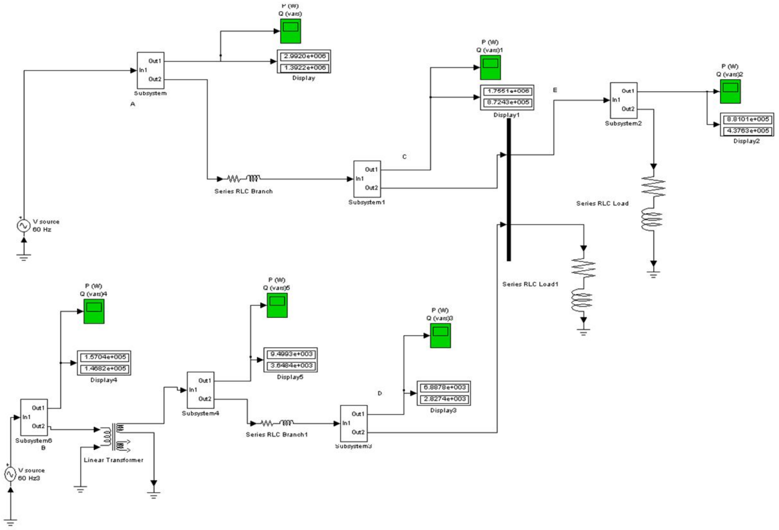

Fig 4: Modelling of simulation at power system after connect (EG) with (BT) and (TL)

III.CALCULATION

1) *Step 1* the single line diagram: represent system by its one line diagram showing

a) *At Steady State*

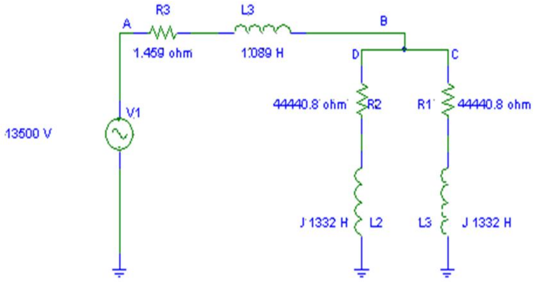

Fig 5: represent single line diagram

This circuit is at steady state to calculate the performing the single phase analysis.

The real power in the two loads are P1 =$10\times 10*6$ MW

1- Reactive power in the two loads are Q1=$3\times 10*6$ MVAR
2- The voltage loads are 13500V
3- The complex power in the load

S1 =P1+JQ1=10× 10*6+J 3× 10*6 MVA = $10.44*10^{6}\angle 16.99$ MVA

The current in the load number 1

I1= $\dfrac{S1}{V}=\dfrac{10.44\times 10*6\angle 16.699}{13.5\times 10*3\angle 0}$ = $773.3333\angle 16.69$ A

Impedance in the load number 1

Z1=$\dfrac{V}{I1}=\dfrac{13.5\times 10*3\angle 0}{773.3333\angle -16.699}$ =17.456 ∠ 16.699 ohm

1- The real power in the two loads are P2=$10\times 10*6$ MW
2- Reactive power in the two loads are Q2=$3\times 10*6$ MVAR
3- The voltage loads are $13.5\times 10*3$ KV

I2= $\dfrac{S2}{V}=\dfrac{10.44X10*6\angle 16.699}{13.5\times 10*3\angle 0}$ = 773.3333 $\angle 16.699$ A

= 773.333× cos ∠ 16.669+J 773.333× sin ∠ 16.669 = 740.719+j 222.212 A

Z2 is Impedance of load number 2

Z2==$\dfrac{V}{I2}=\dfrac{13.5\times 10*3\angle 0}{773.3333\angle 16.699}$ =17.456 ∠ 16.669 Ohm

Z is result of parallel impedance between two loads in the circuit

Z= $\dfrac{ZI\times Z2}{ZI+Z2}$ =8.72 $\angle 16.69$ ohm [Note that the impedance is a complex number] =8.36 +J2.5 ohm

The result of Zequ in the circuit = the loads impedance+ Z line impudence

Zequ=8.36+j 2.5+1.459+j 1.089=10.45 $\angle 20.798$ ohm

The equivalent is found, and with the presence of a voltage source, the total current in the circuit can be calculated.

4-The power in the load 1 is

S2=P2+JQ2 =10× 10*6+J 3× 10*6 MVA = $10.44*10^{6}\angle 16.99$ MVA

I2 is the current in the load number 2

I2= $\dfrac{S2}{V}=\dfrac{10.44X10*6\angle 16.699}{13.5\times 10*3\angle 0}$ = 773.3333 $\angle 16.699$ A

= 773.333× cos ∠ 16.669+J 773.333× sin ∠ 16.669 = 740.719+j 222.212 A

Z2 is Impedance of load number 2

Z2==$\dfrac{V}{I2}=\dfrac{13.5\times 10*3\angle 0}{773.3333\angle 16.699}$ =17.456 ∠ 16.669 Ohm

Z is result of parallel impedance between two loads in the circuit

Z= $\dfrac{ZI\times Z2}{ZI+Z2}$ =8.72 $\angle 16.69$ ohm [Note that the impedance is a complex number] =8.36 +J2.5 ohm

The result of Zequ in the circuit = the loads impedance+ Z line impudence

Zequ=8.36+j 2.5+1.459+j 1.089 =9.449+j3.589=10.45 $\angle 20.798$ ohm

The equivalent is found and also has a voltage supply to calculate the total current in the circuit.

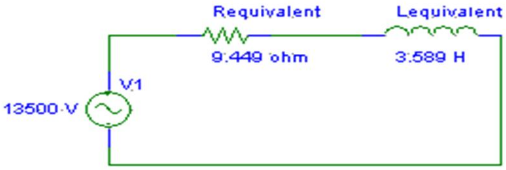

Fig 6: single phase equivalent of circuit

First the source 13500 $\angle 0V$ V is understood to be rms the angle “ $\angle 0$ ” is assigned arbitrarily and is logical choice. The source voltage selected as a phase reference for convenience.

The equevant impedance value in the circuit =10.45 $\angle 20.798$ ohm.

To calculation the maximum current value flowing into the circuit.

$$I=\frac{V \sup \ plt}{Zequ}=\frac{13.5\times 10*3\angle 0}{10.45\angle 20} = 1291.86\angle -20.798 \ \text{A}$$

The “1291.86”is the rms value of the current .the phase angle “20°” tell us the current is 20° in phases behind the source voltage .it is common to say “the current lags the voltage

To calculation the maximum complex power S flowing into the circuit is defined as:

$S = I^* \times V = 1291.86\angle 20.789 \times 13500 \ \angle 0$ VA $=17.44\times 10*6 \ \angle 20.789$ MVA

$=16.38\times 10*6 + J5.964\times 10*6$ M VA

The component of power complex is real and reactive power

$$P=\frac{\operatorname{Im}ax\times V\max}{2}\times\cos\theta$$

The real and reactive power maximum has been found so divided /2 because need the RMS (value average value) the maximum and because very close to supply.

The real power at point A

$$P\ rms=\frac{16.38\times 10*6}{2}=8.194\times 10*6 \ \text{MW}$$

The maximum reactive power in the circuit same point at point A

$$Qrms=\frac{\operatorname{Im}ax\times V\max}{2}\times\sin\theta=\frac{5.964\times 10*6}{2}=J2.98\times 10*6 \ \text{MVAR}$$

To calculate real power and reactive power at point B after voltage drop should know the voltage drop inline.

Voltage drop in line =Zline $\times$ line current

$\Delta V = Z\times I = 1.82\angle 36.737 \times 1291.86\angle -20V = 2351.1852\angle 16.73$ V

Voltage in the point B= voltage supply-voltage drop in the line of the circuit.

$=13.5\times 10*3\angle 0 - 2351.1852\angle 16.73 = 11268.69\angle 3.44$ V

The voltage at point B is lower than the voltage in point A because power loss line.

To calculation complex power at point B

$S=I^*\times V = 1291.86\angle -20 \times 11268.694\angle 3.44$ VA

To complex power is

$=14.55\times 10*6 \ \angle -16.56$ MVA $=13.946\times 10*6 - J4.14\times 10*6$ MVA

The real power is

$$P\ rms=\frac{\operatorname{Im}ax\times V\max}{2}\times\cos\theta=\frac{13.946\times 10*6}{2}=6.982\times 10*6 \ \text{MW}$$

The reactive power is point B

$$Q\ rms=\frac{\operatorname{Im}ax\times V\max}{2}\times\sin\theta = -2.073\times 10*6 \ \text{MVAR}$$

The real and reactive power at point B is lower than the real and reactive at point A due to Voltage drop in line that mean power quality impact of changing the voltage and current.

The value of impedance loads is same. So, the main current well is speared as the same:

Total current =load current at impedance load [1] +load current at the impedance load [2]

The current for each impedance =total current-the current for other branch

$=\frac{1291.86\angle-20}{2}=645.86\angle-20$ A

The current for each branch = $645.93\angle-20$ A

The complex power is

S=I*$\times V$ = $645.93\angle-20\times 11268.69\angle 3.44$ $=7.278\times 10*6\angle-16.56$ MVA

$=6.976\times 10*6$ -J$2.07\times 10*6$ MVA

The real power is

P=$3.488\times 10*6$ MW

The reactive power is

Q=-$1.04\times 10*6$ MVAR

To find real power and reactive power in branch D so the current and the voltage

Are same the current for each branch =$645.93\angle-20$ A

The complex power is

S=I*$\times V$ = $645.93\angle-20\times 11268.69\angle 3.44$ M VA =$7.278\times 10*6\angle-16.56$ MVA

$=6.976\times 10*6$ -J$2.07\times 10*6$ MVA

The real power is

P=$3.488\times 10*6$ MW

The reactive power is

Q= -$1.035\times 10*6$ MVAR

TABLE I

THE FIRST CASE

NODE	CALCULATION	SIMULATION	DIFFERENT S-C	ERRO=$\frac{S-C}{S}$	%
P A	$8.194\times 10*6$ MW	$8.1821\times 10*6$ MW	-11900	-0.00145	-0.145
QA	$2.98\times 10*6$ MVAR	$2.9978\times 10*6$ MVAR	17800	0.00593	0.593
PB	$6.982\times 10*6$ M W	$6.9663\times 10*6$ MW	-15700	-0.00225	-0225
QB	$2.073\times 10*6$ MVAR	$2.0899\times 10*6$ MVAR	16900	.000808	0.0808
PC	$3.488\times 10*6$ MW	$3.4832\times 10*6$ MW	-4800	-0.0013	-0.13
QC	$1.04\times 10*6$ MVAR	$1.0449\times 10*6$ MVAR	4900	0.00466	0.466
PD	$3.488\times 10*6$ M W	$3.4832\times 10*6$ MW	-4800	-0.0013	-0.13
QD	$1.04\times 10*6$ MVAR	$1.0449\times 10*6$ MVAR	4900	0.00466	0.466
VOLTAGE	11268.69 V	11268 V	-0.69	-0.00006	-0.006

2) *Step 2*, system a single line diagram: represent system by its one line diagram showing generator and transformer

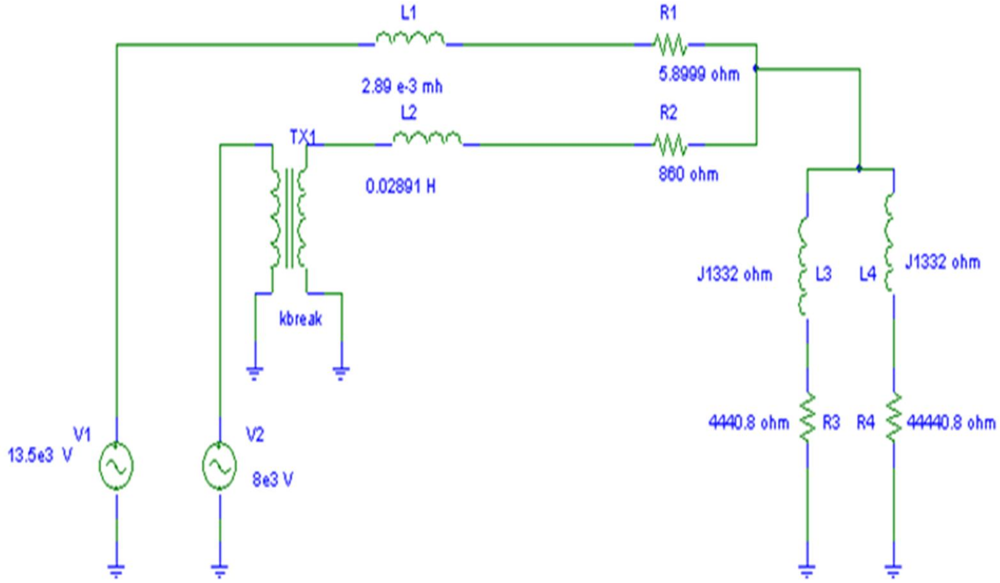

Fig 7: Represent single line diagram with generation and transform

From first step can calculation the Z loads =8.36+j2.5

At this step calculation, the impedance Zt is the parallel impedance between two impedance in the circuit.

$$Zt=\frac{Z1\times Z2}{Z1+Z2}=\frac{1.82\angle 36.71\times 18.2\angle 36.7}{1.82\angle 36.61+18.2\angle 36.7}=1.693\angle 38.564 \text{ ohm}$$

The result of Zequ in the circuit = the loads impedance+ Zt line impudence

Zequ in this circuit $=1.693\angle 38.564+8.725\angle 16.64=10.296\angle 20$ ohm

To calculation the maximum current value flowing into the circuit

$$\text{Maximum in the circuit}=\frac{voltage\ \sup\ pLy}{Zequ}=\frac{13500\angle 0}{10.296\angle 20}=1131\angle -20\ A$$

To calculation the maximum complex power S flowing into the circuit is defined as:

$S=I^{*}\times V\ \sup\ ply$ MVA $=1131.953\angle 20\times 13500\angle 0$ MVA $=15.228\times 10*6+J6.05\times 10*6$ MVA

The real power is at point A

$$Prms=\frac{\text{Im}\ ax\times V\ \max}{2}\times\cos\theta=\frac{15.228\times 10*6}{2}=7.614\times 10*6 \text{ MW}$$

The reactive power in circuit at point A

$$Qrms=\frac{\text{Im}\ ax\times V\ \max}{2}\times\sin\theta=\frac{6.05\times 10*6}{2}=3.025\times 10*6 \text{ MVAR}$$

The total current separates two branches indented on the value of impedance in the branch can be known.

The current in impedance Z1= total current $\times\dfrac{Z2}{Z1+Z2}$

$$=1311.953\angle 20\times\frac{18.2\angle 36.71}{1.82\angle 36.71+18.2\angle 36.7}=1193.87\angle -20 \quad \text{A}$$

The current in impedance Z2 =total current-current in Z1

$=1311.953\angle 20-1193.87\angle -20$ A $=118.083\angle -20$

Calculate the voltage drop in branch (1)

Voltage drop in branch (1) = current branch $\times$ impedance branch

$$\Delta v=1193.953\times\angle -20\times 1.82\angle 36.7=2172.99\angle 16.7 \text{ A}$$

The voltage in point B= voltage supply –voltage drop

=13500$\angle 0 - 2172\ .99\ \angle 16\ .7$ V =11454.2+j732.5 V =11477.59$\angle 3.659$ V

To find the complex power in point B

S=I* $\times$Vat point B =1193.953$\angle 20 \times 11477\ \ .59 \angle 3.659$ MVA

S at point B =13.7$\times$ 10 * 6$\angle 23\ .659$ MVA

S=12.5$\times$ 10 * 6 + j5.49 $\times$ 10 * 6 MVA

The real power at point B=$\dfrac{12.5\times 10 * 6}{2}$ =6.25$\times$ 10 * 6 MW

The reactive power at point B=$\dfrac{5.49 \times 10 * 6}{2}$ =2.745$\times$ 10 * 6 MVAR

The current at second branch Z2= total current-the current in branch Z1

=1311.953$\angle 20 - 1193.87 \angle - 20$ =118.083$\angle - 20$ A

To find voltage at point Cit must be find voltage drop in branch Z2

Voltage drop at branch Z2=the current in branch Z2$\times$ impedance of this line

Δv=118.083$\angle - 20 \times 18.2 \angle 36\ .7$ =2149.1106$\angle 16\ .7$ V

The voltage at point C = voltage supply –voltage in this branch

=13500$\angle 0$ -2149.1106$\angle 16\ .7$ =11458.2$\angle 3.089$ V

To calculate the complex power at point C

S at point C =I*$\times$voltage at C

=118.083$\angle 20 \times 11458\ \ .2 \angle 3.089$ =1353018.631$\angle 23\ .089$ VA =1.2446$\times$ 10 * 6 + J 5.30 $\times$ 10 * 5

The real power at point C

P=$\dfrac{1.2446 \times 10 * 6}{2}$ =0.6223$\times$ 10 * 6 MW

The reactive power at point C

Q=$\dfrac{5.3 \times 10 * 5}{2}$ =0.265$\times$ 10 * 6 MVAR

From KRASOVE law the currents around any point =total current in this point

1193.87$\angle - 20$ +118.083$\angle - 20$ =1311.953$\angle 20$ A

As you know the loads are equal the current well be separate between two loads

The current each branch =$\dfrac{1131\ \ .953 \angle 20}{2}$ =655.9765 $\angle 20$ A

The voltage at the loads approximately the same the voltage at point B =11477.59 7the voltage at point C =11458.28 the average =11467.895 V

The complex power, real power and reactive power are the same at loads

The complex power at point D and E

S=I*$\times V$

S at points D and E=655.9765$\angle - 20 \times 11467\ \ .895 \angle 3.374$ =7522663.891$\angle - 16\ .626$

=7.208$\times$ 10 * 6 -J 2.152$\times$ 10 * 6 MVA

The real power P at points D and E are equal

Prms=$\dfrac{7.208 \times 10 * 6}{2}$ = 3.604$\times$ 10 * 6 MW

The reactive power at points D and E are equal

Qrms=$\dfrac{- 2.152 \times 10 * 6}{2}$ = -1.076$\times$ 10 * 6 MVAR

TABLE III
The second case after connect the embedded generation with booster transformer

NODE	CALCULATION	SIMULATION	DIFFERENT S-C	ERRO $=\frac{S-C}{C}$	%
P A	7.614× 10 * 6 M W	2.9920× 10 * 6 M W	-766500	-0.001	-0.1
QA	3.025M× 10 * 6 VAR	1.3922× 10 * 6 MVAR	-266700	-0.0976	-9.76
PB	6.25× 10 * 6 MW	1.5704× 10 * 5 W	-23710	-0.00363	0.363
QB	2.745× 10 * 6 MVAR	1.4682× 10 * 5 VAR	14830	.07	7
PC	0.6223× 10 * 6 M W	1.7551× 10 * 6 M W	-9500	-0.00145	0.145
QC	0.265× 10 * 6 MVAR	8.7243× 10 * 6 MVAR	-6100	-0.00311	-0.31
PD	3.604× 10 * 6 M W	6.8878× 10 * 3 KW	-3800	-0.00105	-0.105
QD	-1.076× 10 * 6 MVAR	2.8274× 10 * 3 VAR	-8100	-0.00751	-0.751
PE	3.604× 10 * 6 MW	8.8101× 11110 * 5 W	-3800	-0.00105	-0.105
QE	-1.076× 10 * 6 MVAR	4.3763× 10 * 5 VAR	-3800	-0.00751	-0.751
Voltage	11467.895 V	11441 V	-26.895	-0.00235	-0.023

IV. CONCLUSIONS

Voltage sag is most important in power quality of a power system. That can see the effect of voltage sag and power quality on the network; there is not a very big difference between the calculation and simulation in section one, only a small difference. The value is not accurate when the calculating or using the instruments.

In the first step in calculation have been found the real power and reactive power are higher because they are very close to the power supply, and lower in the bus bar in due to line power loss. This means power quality is affected by the voltage at the end of system when the current is separate from the load.

The real and reactive power is also reduced due to the current, meaning that the power quality is impacted by current and voltage. Also, with this problem has been found low power for customers.

Table I tells us the real power and reactive power is bigger at the point of sending than at receiving, due to line power loss. The magnitude and direction of the flow of real power on a line depends on the phase angle between the sending end voltage and the receiving end voltage. Power flows from the end with the leading voltage to the end with lagging voltage. The magnitude of power flowing down the line increases with an increasing phase angle. The magnitude and direction of the reactive power flow of on a line depends on the difference in magnitude between the sending end voltage and the receiving end voltage. Reactive power flows from the end with higher voltage to the end with the lower voltage. The magnitude of reactive power increases with an increasing voltage difference.

This problem affects the performance the system. To avoid this problem, connecting the embedded generation very close to customers will improve the power quality, and also connecting a setup transformer with embedded generation to compensate for the voltage dip in transmission line to keep the customers' voltage normal.

Table II tells us about changing the system. In this case have been founded a very big difference between calculation and simulation, in real power and reactive power, but the voltage is approximately the same. If compare the first and second steps, the value of the power quality is different.

In the second case have been found the voltage improved for customers, and the real and reactive power also improved.

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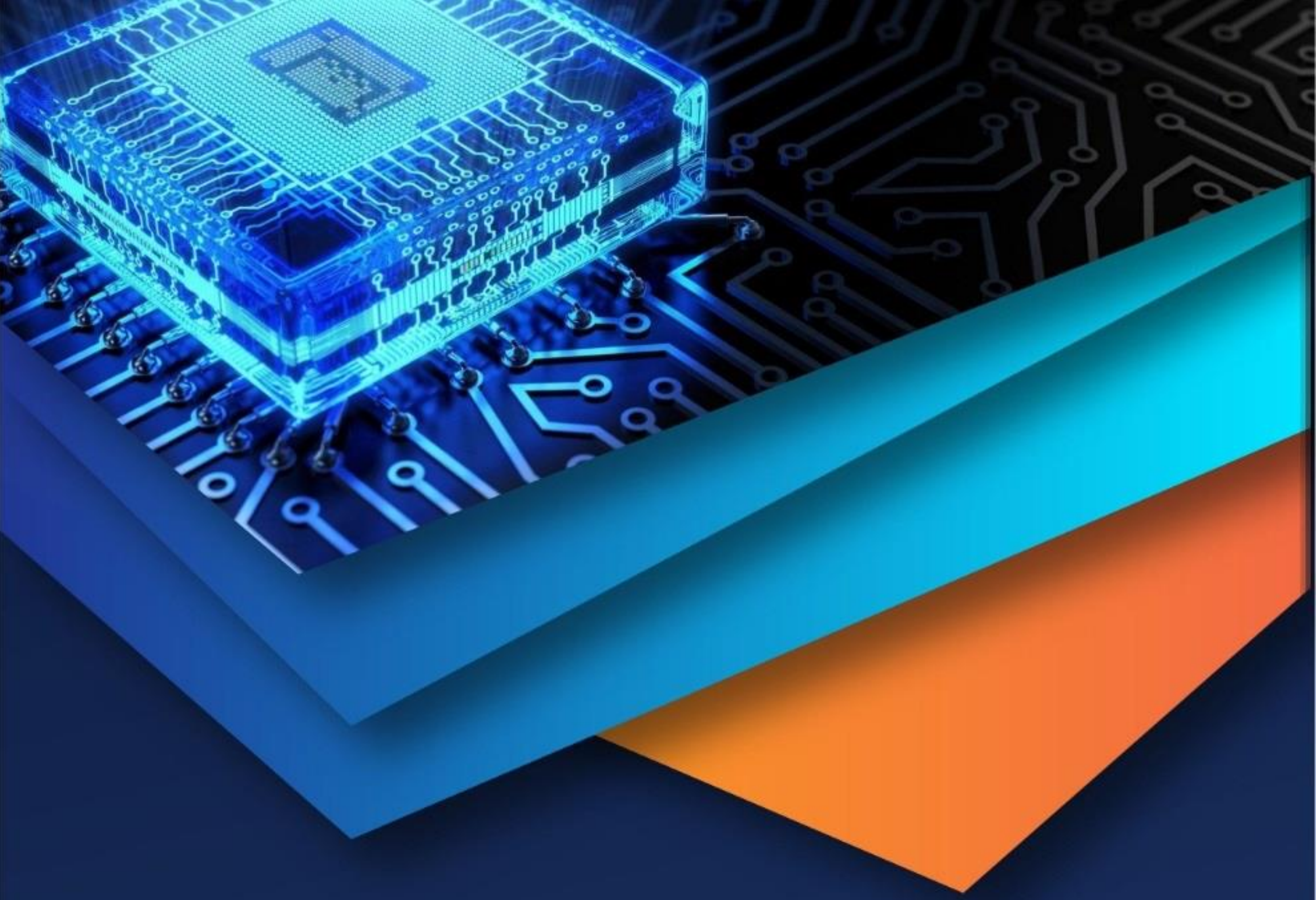

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