LOAD BALANCING AND POWER FACTOR CORRECTION IN POWER DISTRIBUTION SYSTEM

Bachelor of Technology in Electrical Engineering

BY

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This report project has been written by myself.

Signature of the Student

Certified that the student has performed the project work under my supervison.

Signature of the Supervisor

CERTIFICATE

This is to certify that the work on the thesis entitled **Load balancing and power factor correction in distribution system** by **Pushanjeet Mishra** and **Abhisek Kumar Panda** is a record of original research work carried out under my supervision and guidance for the partial fulfillment of the requirements for the degree of **Bachelor in Technology** in the department of **Electrical** Engineering, **National Institute of Technology, Rourkela**. Neither this thesis nor any part of it has been submitted for the award of any degree elsewhere.

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ABSTRACT

The project presents an approach for load balancing and power factor correction. First we have considered a three phase grounded load system where the supply is a three phase balanced supply. Before balancing the load and correcting the power factor it is necessary to compensate the neutral current. We propose three schemes for neutral current balancing. After that the system becomes equivalent to ungrounded star connected load. Now to carry power factor correction and load balancing we need to convert the load to delta connected load. Hence we carry out star-delta transformation and we carry out our main objective through the proposed methods.

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I. INTRODUCTION

For our convenience we require distortion less voltage and current supply. Usually there are distortions in this waveforms because of the presence of non linear loads.

It is important to compensate reactive power due to non linear loads. Over the years many methods have been proposed for carrying out this proposed work. Our main aim is to generate reference current waveform, which will compensate the load harmonics and enhance the power factor.

Our main objective is to first transform the system from three phase four wire unbalanced load to three phase three wire unbalanced load and then carry out the necessary power factor and load balancing calculations. Three different schemes has been proposed for this method and then a common scheme has been proposed for load balancing and power factor correction.

II. BACKGROUND AND LITERATURE REVIEW

Load Compensation

It is necessary to manage the reactive power to improve the power factor and the quality of supply Load compensation is the major player in it.

The main objectives in load compensation are:

- Improved voltage profile
- Power factor improvement
- Balanced load.

It is important to maintain the voltage profile within +-5% of the rated value. The main reason for voltage variation is unbalanced parameters in the generation side and consumption side. If the reactive power that is being consumed is greater than what is being generated then there is a definite chance of increased voltage levels. But if both of them are equal then the coltage levels become flat. Hence in order to maintain a flat voltage profile we have to determine the active power transfer capability of the system and the necessary reactive power to be compensated has to be carried out using shunt compensating elements i.e either a capacitor or an inductor.

Power factor correction

An unity power factor is desirable for better economic and technical operation of the system. Usually p.f correction means to generate reactive power as close as possible to the load which requires it rather than generate it at a distance and transmit it to the load, as this results not only in large conductor size but also in increased losses.

Load balancing

A very important concept of load compensation is load balancing. It is desirable to operate the three phase system under balanced condition as unbalanced operation results in flow of negative sequence current in the system and is highly dangerous especially for rotating machines.

An ideal load compensator would perform the following functions,

- It would provide controllable and variable reactive power almost instantaneously as required by the load.
- It should operate independently in all three phases.
- It should maintain constant voltage at its terminal.

Harmonic distortion

Harmonic distortion is the change in the waveform of the supply voltage from the ideal sinusoidal waveform. It is caused by the interaction of distorting customer loads with the impedance of the supply network. Its major adverse effects are the heating of induction motors, transformers and capacitors and overloading of neutrals. Power factor correction capacitors can amplify harmonics to unacceptable values in the presence of harmonic distortion. Standards specify the major harmonic voltages which can occur on the network, 5% total harmonic distortion being typical.

Power system harmonics

Power system harmonics are integer multiples of the fundamental power system frequency. Power system harmonics are created by non linear devices connected to the power system. High levels of power system harmonics can create voltage distortion and power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors.

Active power filters

Active power filters are simply power electronic converters specifically designed to inject harmonic currents to the system. Active power capabilities include:

- Eliminating voltage and current harmonics
- Reactive power compensation
- Regulating terminal voltage
- Compensating the voltage flickering

III. METHODOLOGY

III.I System Overview:

In our system we have considered a balanced three phase supply feeding the unbalanced load. The supply voltages are taken as:

$V_a = |V| \angle 0 \quad V_b = |V| \angle 120 \quad V_c = |V| \angle 240.$

First we have considered a three phase unbalanced grounded load system, we present three schemes for neutral current compensation and then three-phase three wire unbalanced load will be compensated using a common scheme. For the first scheme we consider phase b and c, second scheme selects phase a and b and third scheme selects phase a and c for neutral current compensation. The current carried away by neutral, $I_{neutral}$ is given by the summation of I_{na}, I_{nb}, In0. $I_{neutral}$ will be neutralized by injecting a current I_{n0} equal in magnitude and 180 degrees out of phase from $I_{neutral}$ where I_{n0} stands for neutral current compensating current.

The load becomes equivalent to three phase three wire unbalanced load after neutral current compensation, this system is then transformed to equivalent delta connection. We select two sets of compensating elements, one for power factor correction and the other for load balancing of this equivalent delta connection.

III.II Neutral current compensation of three phase unbalanced grounded loads

III.II.I Scheme 1:

The above scheme proposes a method for neutral current compensation in phase b and phase c. The type of compensating element to be chosen will depend upon the phase angle of the neutral compensating current I_{n0} i.e σ. Reactive elements chosen for b and c phases will be decided by angles ø and μ. The angles ø and μ are the angles for compensating elements $Z_{bc}$and Z_{cc}. These two impedances being lossless reactive elements (either capacitive or inductive) thus, these angles ø and μ will be +-90 degrees. If -90 degrees is selected then the element is a inductor or if +90 degrees is selected the selected element is an capacitor.

For 30 deg<σ< 150 deg, ø =-90 deg μ =-90 deg.

For 150 deg<σ< 210 deg, ø =+90 deg μ =-90 deg.

For 210 deg<σ< 330 deg, ø =+90 deg μ =+90 deg.

For 330 deg<σ< 360 deg, ø =-90 deg μ =+90 deg.

Neutral current between the two phases is equal to I_{bc} and I_{cc} where these are the current carried by the reactance's in phase b and c respectively. We decompose the reactances on phase and quadrature axis of phase voltage V_a and equate them to corresponding components of I_{n0} , the equations obtained are:

$$|I_{n0}| \cos(\sigma) = |I_{bc}| \cos(120+ ø) + I_{cc}| \cos(240+ \mu) \ldots \quad (1)$$

$$|I_{n0}| \sin(\sigma) = |I_{bc}| \sin(120+ ø) + I_{cc}| \sin(240+ \mu) \ldots \quad (2)$$

$$|I_{n0}| = |I_{neutral}| \ldots \quad (3)$$

On solving the equations for $|I_{bc}|$ and $|I_{cc}|$ we get:

$$|I_{bc}| = |I_{n0}| \sin(240+ \mu - \sigma) / \sin(120+ \mu - ø).$$

$|I_{cc}| = |I_{n0}| \sin(120+ ø -σ) /\sin(-μ + ø -120)$.

We obtain the below susceptances:

$|B_{bc}| = |I_{bc}| \sin(ø)/V$ mag.

$|B_{cc}| = |I_{cc}\sin(μ)/V$ mag.

The above susceptances are put across phase b and phase c and the system neutral current is $I_{al}+ I_{bl}+I_{cl}+I_{bc}+I_{cc}=0$.

Neutral compensated load now becomes equivalent to:

$Z_a= Z_{al}$; $Z_b=Z_{bl}.Z_{bc}/(Z_{al}+Z_{bc})$; $Z_{cn}= Z_{cl}.Z_{cc}/(Z_{cl}+Z_{cc})$.

III.II.II Scheme 2:

This scheme below provides neutral current compensation in phases a and b for a 3 phase 4 wire unbalanced load. The reactive elements will be placed in phases a and b for neutral current compensation. The angle λ and ø are the angles of lossless reactive elements that are to be connected across phase a and phase b for neutral current compensation and may be either $+90^0$ or -90^0. Angles λ and ø will depend on the value of σ as follows.

For $30^0<σ<90^0$, $λ=+90^0$, $ø=-90^0$

For $90^0<σ<210^0$, $λ=+90^{0,}$ $ø=+90^0$

For $210^0<σ<270^0$, $λ=-90^0$, $ø=+90^0$

For $270^0<σ<360^0$, $λ=-90^0$, $ø=-90^0$

If angle λ or ø is positive then capacitor if negative then inductor will be connected in the respective phases. These reactive elements will carry phase currents I_{ac} and I_{bc} in phases a and b respectively. The currents I_{ac} and I_{bc} are decomposed along phase and quadrature axis and the equations obtained are as follows:

$In0\cos\sigma = I_{ac}\cos\lambda + I_{bc}\cos(120+ø)$;….. (1)

$In0\sin\sigma = I_{ac}\sin\lambda + I_{bc}\sin(120+ø)$;…. (2)

Neutral current in compensating phases a and b is given by I_{ac} and I_{bc}. On solving above equations:

$I_{ac}=In0\sin(120+ø-\sigma)/\sin(120^0+ø-\lambda)$;

$I_{bc}=In0\sin(\lambda-\sigma)/\sin(\lambda-ø-120^0)$;

$I_{ac}=I_{ac}<\lambda$; $Z_{ac}=V/I_{ac;}$

$I_{bc}=I_{bc}<(120+ø)$; $Z_{bc}=V/I_{bc;}$

The corresponding susceptances are $B_{ac}=I_{ac}\sin(\lambda/V)$; $B_{ac}=I_{bc}\sin(ø/V)$

The values of Z_{ac} and Z_{bc} make the system equivalent to three phase ungrounded star connected. Supply neutral current becomes zero as:

$I_{al} + I_{bl} + I_{cl}+ I_{ac}+ I_{bc}=0$

Equivalent neutral compensated load now becomes:

$Z_a=Z_{al}Z_{ac}/(Z_{al}+Z_{ac})$; $Z_b=Z_{bl}Z_{bc}/(Z_{bl}+Z_{bc})$; $Z_c=Z_{cl.}$

III.II.III Scheme 3:

The below scheme considers phases a and c for neutral current compensation. The values and type of susceptances to be connected across phase a and c will depend upon the following method:

For $0^0<\sigma<90^0$ and $330^0<\sigma<360^0$, $\lambda=+90^0$, $\mu=-90^0$

For $90^0<\sigma<150^0$, $\lambda=+90^{0,}$ $\mu=-90^0$

For $150^0<\sigma<270^0$, $\lambda=-90^0$, $\mu=-90^0$

For $270^0<\sigma<330^0$, $\lambda=-90^0$, $ø=+90^0$

On decomposing the currents along phase and quadrature axis we obtain the following equations:

$In0\cos\sigma=I_{ac}\cos\lambda+I_{cc}\cos(240^0+\mu)$;….. (1)

$In0\sin\sigma=I_{ac}\sin\lambda+I_{cc}\sin(240^0+\mu)$;…… (2)

$In0=I_{neutral}$…… (3)

Solving the above equations we obtain:

$I_{ac}=In0\sin(240+\mu-\sigma)/\sin(240+\mu-\lambda)$;

$I_{cc}=I_a\sin(\lambda-\sigma)/\sin(\lambda-\mu-240^0)$;

$I_{ac}=I_{ac}<\lambda$; $Z_{ac}=V/I_{ac;}$

$I_{cc}=I_{cc}<(240^0+\mu)$; $Z_{cc}=V/I_{cc;}$

The susceptances obtained are $B_{ac}=I_{ac}\sin(\lambda/V)$; $B_{cc}=I_{cc}\sin(\mu)/V$. The above values of Z_{ac} and Z_{cc} make the system equivalent to three phase ungrounded star connected. Supply neutral current becomes zero as:

$I_{al} + I_{bl} + I_{cl} + I_{ac} + I_{cc} = 0$

Now the load becomes equivalent to:

$Z_a = Z_{al}Z_{ac}/(Z_{al}+Z_{ac})$; $Z_b = Z_{bl}$; $Z_{c=}\ Z_{cl}.Z_{cc}/(Z_{cl}+Z_{cc})$.

Hence, from the above three schemes neutral current is being compensated and the system is converted to a three phase ungrounded unbalanced load system. A common scheme has been proposed for power factor correction and load balancing.

III.III Power factor correction and load balancing of unbalanced load

After carrying out the neutral current compensation from the above schemes, now the load becomes equivalent to ungrounded load, then we carry out the star-delta transformation of the above loads as follows:

$Y_{ab'}=Z_c/(Z_aZ_b+ZbZ_c+Z_aZ_c)$

$Y_{bc'}=Z_a/(Z_aZ_b+Z_bZ_c+Z_aZ_c)$

$Y_{ca'}=Z_b/(Z_aZ_b+Z_bZ_c+Z_aZ_c)$

The load now becomes unbalanced delta connected load. Hence loads such as equivalent delta connected or delta connected are transformed in the following manner. For power factor correction a set of susceptances are connected across loads. These susceptances are determined by the following manner. We separate the real and imaginary parts of admittances $Y_{ab'}$,$Y_{bc'}$ and $Y_{ca'}$.

B_{ab0}=-Img($Y_{ab'}$); B_{bc0}=-Img($Y_{bc'}$); B_{ca0}=-Img($Y_{ca'}$); $G_{ab'}$=Real($Y_{ab'}$); $G_{bc'}$=Real($Y_{bc'}$); $G_{ca'}$=Real($Y_{ca'}$)

After finding out the susceptances B_{ab0}, B_{ac0}, $B_{bc0,}$ connections are made across the loads for power factor correction by realising the reactive part of the loads. To balance the loads susceptances $B'_{ab2,}$ $B'_{bc2,}$ B'_{ca2} are connected across phase a-b, b-c and c-a. To determine $B'_{ab2,}$ $B'_{bc2,}$ B'_{ca2} following calculations are made:

$I_a=I<0^0$; $I_b=<120^0$; $I_c=I<240^0$

Ohms Law states that;

$I_{ab'}$=(Va-V_b)($G_{ab'}$+jB'$_{ab2}$);

$I_{bc'}$=(V_b-V_c)($G_{bc'}$+jB'$_{bc2}$);

$I_{ca'}$=(V_c-Va)($G_{ca'}$+jB'$_{ca2}$);

Kirchoffs law at nodes 2 and 3 gives:

$I_{a'}=V_{ab'}(G_{ab'}+jB'_{ab2})-V_{ca'}(G_{ca'}+jB'_{ca2})$ ...(1)

$I_{b'}=V_{bc'}(G_{bc'}+jB'_{bc2})-V_{ab'}(G_{ab'}+jB'_{ab2})$ …(2)

$I_c=V_{ca'}(G_{ca'}+jB'_{ca2})-V_{bc'}(G_{bc'}+jB'_{bc2})$ …(3)

Above equations are calculated and we obtain the following :

$I=|V|/(G_{ab'}+G_{bc'}+G_{ca'})$

$B'_{ab2}=I/(3^{1/2}|V|)-G_{ab'}/3^{1/2}-2G_{ca'}/3^{1/2}$

$B'_{ca2}=-I(3^{1/2}|V|)+2G_{ab'}/3^{1/2}+G_{ca'}/3^{1/2}$

$B'_{bc2}=-I/(2*3^{1/2}*|V|)+3^{1/2}G_{ca'}/2-B'_{ca2}/2$

For both power factor correction and load balancing we connect the suscpetances in parallel and the equivalent susceptances obtained are as follows:

$B_{ab'}=B_{ab0}+B'_{ab2}$, $B_{bc'}=B_{bc0}+B'_{bc2}$, $B_{ca'}=B_{ca0}+B'_{ca2}$

IV. TABULATION AND CALCULATION

FIRST SCHEME CALCULATIONS:

Current calculations (in A):

I_{n0}=	43.87∟306.15	I_{cl}=	127.87∟-240
I_{al}=	81.521	I_{bc}=	20.48∟210
I_{bl}=	86.95∟-120	I_{cc}=	50.36∟330

Load impendances and compensating impendances in (ohm) in first scheme:

Z_{al}=	2.821	Z_{bc}=	11.23∟-210
Z_{bl}=	2.65∟120	Z_{cc}=	4.56∟-330
Z_{cl}=	1.79∟240	Z_a=	81.52
Z_b=	2.19∟125	Z_c=	2.6∟-103.43

From the value of σ the angles ø comes to be -90 and µ come to be +90. Hence for neutral current compensation capacitance is connected across the loads in phase b and c.

Capacitance values:

L_{bc}=	10.3mH
C_{cc}=	205.4µF

Compensation of three phase unbalanced grounded load in 1^{st} Scheme

Power factor correction/reactive power compensation	Compensating elements for Load Balancing	Per phase power(kw) and Current(A)
C_{ab0}=258.51µF	C'_{ab2}=70.60µF	P_{phase}=20.11; I_{sa}=77.90<0^0 I_{phase}=77.90
C_{bc0}=289.60µF	C'_{bc2}=38.80µF	I_b=77.90<120^0
C_{ca0}=151.80µF	L'_{ca2}=93.12mH	I_c=77.90<240^0

SECOND SCHEME CALCULATIONS:

Current calculations (in A):

I_{n0}=	43.87∟306.15	I_{cl}=	127.87∟-240
I_{al}=	81.521	I_{ac}=	50.35∟-90
I_{bl}=	86.95∟-120	I_{bc}=	29.88∟30

The compensating elements to be connected across the phase a and b are given in the table below:

L_{ac}=	49.3mH
L_{bc}=	8.51mH

Compensation of three phase unbalanced grounded load in 2nd scheme

Power factor/reactive power compensation	Compensating Elements for Load Balancing	Per phase power(kW) & Current (A)
C_{ab0}=329.71μF	C'_{ab2}=66.31μF	P_{phase}=20.11; I_a=77.90<0^0 I_{phase}=78.72
C_{bc0}=355.70μF	C'_{bc2}=41.20μF	I_b=77.90<120^0
C_{ca0}=219.90μF	L'_{ca2}=93.40mH	I_c=77.90<240^0

THIRD SCHEME CALCULATIONS:

Current calculations (in A)::

I_{n0}=	43.87∟306.15	I_{cl}=	127.87∟-240
I_{al}=	81.521	I_{ac}=	20.48∟-90
I_{bl}=	86.95∟-120	I_{cc}=	51.75∟330

The compensating elements to be connected across phase a and c are given in the table below:

C_{ac}=	978.8μF
C_{cc}=	1191.2μF

Compensation of three phase unbalanced grounded load in 3rd scheme

Power factor/reactive power compensation	Compensating Elements for Load Balancing	Per phase power (kW) & Current (A)
L_{ab0}=152.64mH	C'_{ab2}=66.61μF	P_{phase}=20.11; I_a=77.90<0^0 I_{phase}=77.90
L_{ab0}=48.21mH	C'_{bc2}=22.81μF	I_b=77.90<120^0
L_{ca0}=52.51mH	L'_{ac2}=113.65mH	I_c=77.90<240^0

Compensation of three phase star connected ungrounded load

Load Specifications	Equivalent Delta Connected Load	For Power Factor/Reactive Power Compensation
Z_a=3.43<36.8^0	$Z_{ab'}$=10.83<12.9^0	B_{ab0}=0.0195, C_{ab0}=382.8μF
Z_b=3.33<0^0	$Z_{bc'}$=7.19<7.86^0	B_{bc0}=0.01875, C_{bc0}=59.68μF
Z_c=2.20<31.7^0	$Z_{ca'}$=7.80<44.6^0	B_{ca0}=0.0919, C_{ca0}=292.53μF

Load Balancing Calculations

Compensating Elements	Per Phase Power(kw) and Current(A)
C_{ab2}=83.74µF	P_{phase}=21.46; I_a=79.80<0^0
C_{bc2}=10.72µF	I_{phase}=79.80; I_b=79.80<120^0
L_{ca2}=109.88mH	I_c=79.80<240^0

Compensation of Three Phase Unbalanced Delta connected Load

Load Specifications	Equivalent Delta Connected Load	For Power Factor/Reactive Power Compensation
$P_{ab'}$=26kW 0.81pf	$Z_{ab'}$=11.33<36.9^0	C_{ab0}=183.81µF
$P_{bc'}$=21kW 1.0pf	$Z_{bc'}$=10.18<0^0	C_{bc0}=0.00µF
$P_{ca'}$=24kW 0.86pf	$Z_{ca'}$=7.48<31.8^0	C_{ca0}=255.62µF

Load Balancing Calculation

Compensating Elements	Per phase power(kW) & current(A)
L’$_{ab2}$= 213.3mH	$P_{phase\,=}$ 20.11; I_a=77.71<0^0
C’$_{bc2}$= 94.89µF	I_{phase}= 77.71; I_b=77.74<120^0
L’$_{ca2}$=213.4mH	I_c= 77.74<240^0

CIRCUIT DIAGRAM AND SIMULATIONS

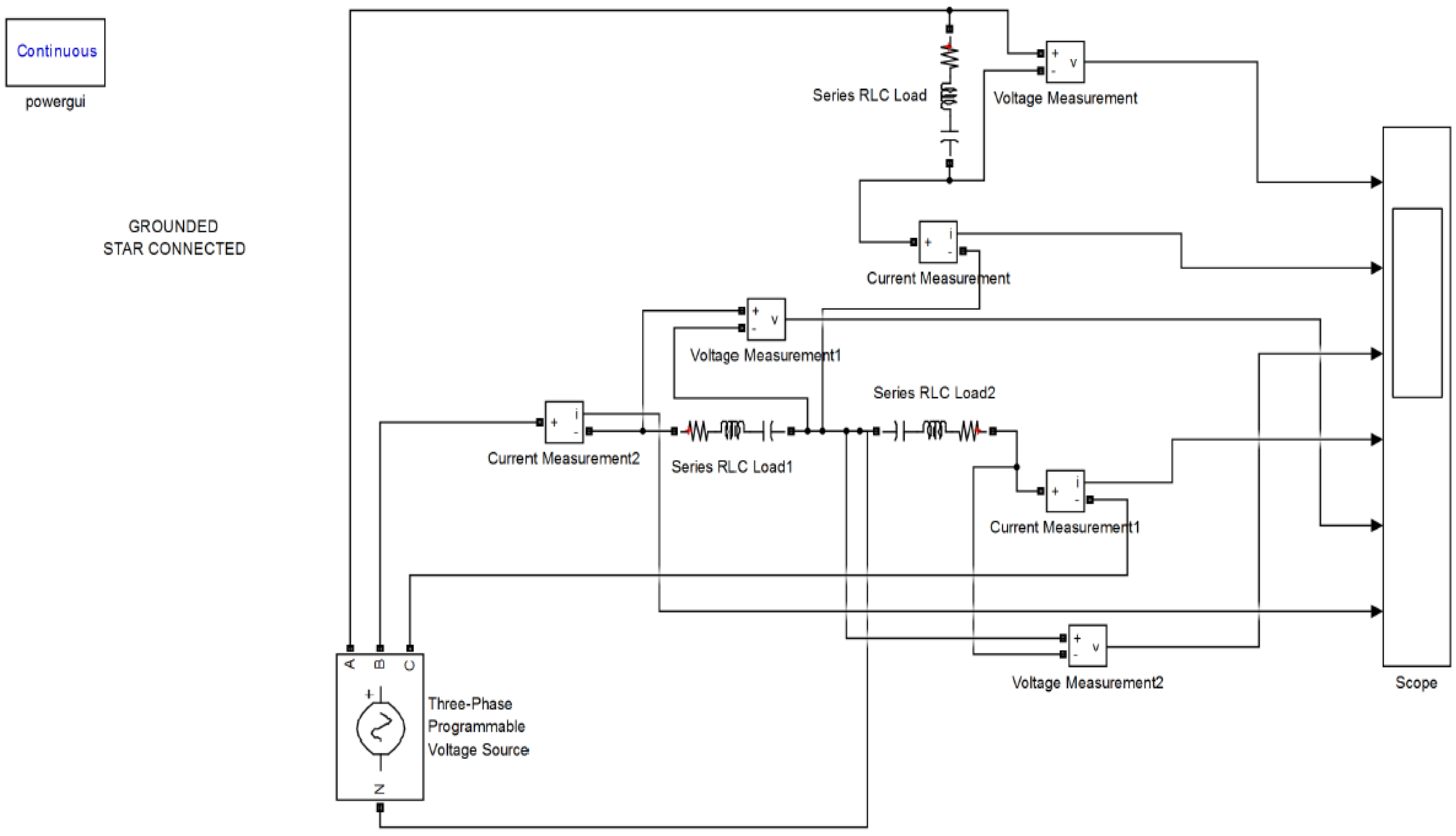


Fig 1. Grounded star connected system

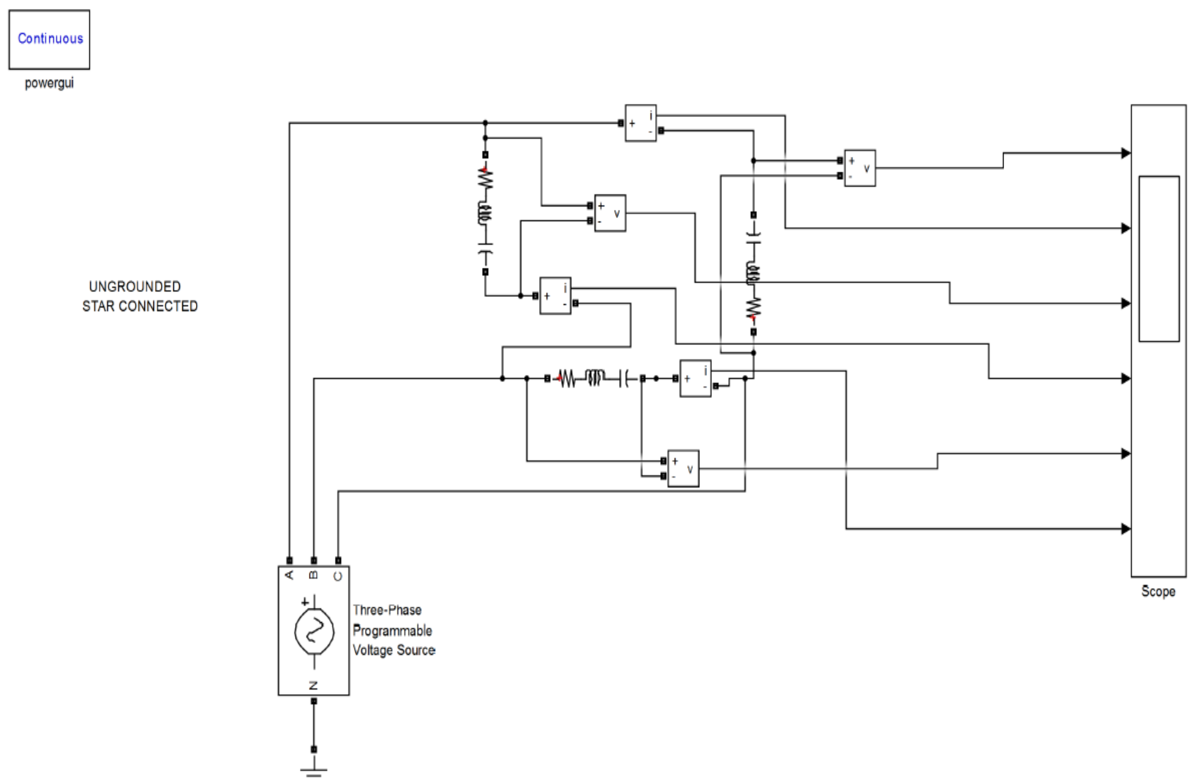


Fig 2. Ungrounded star connected system.

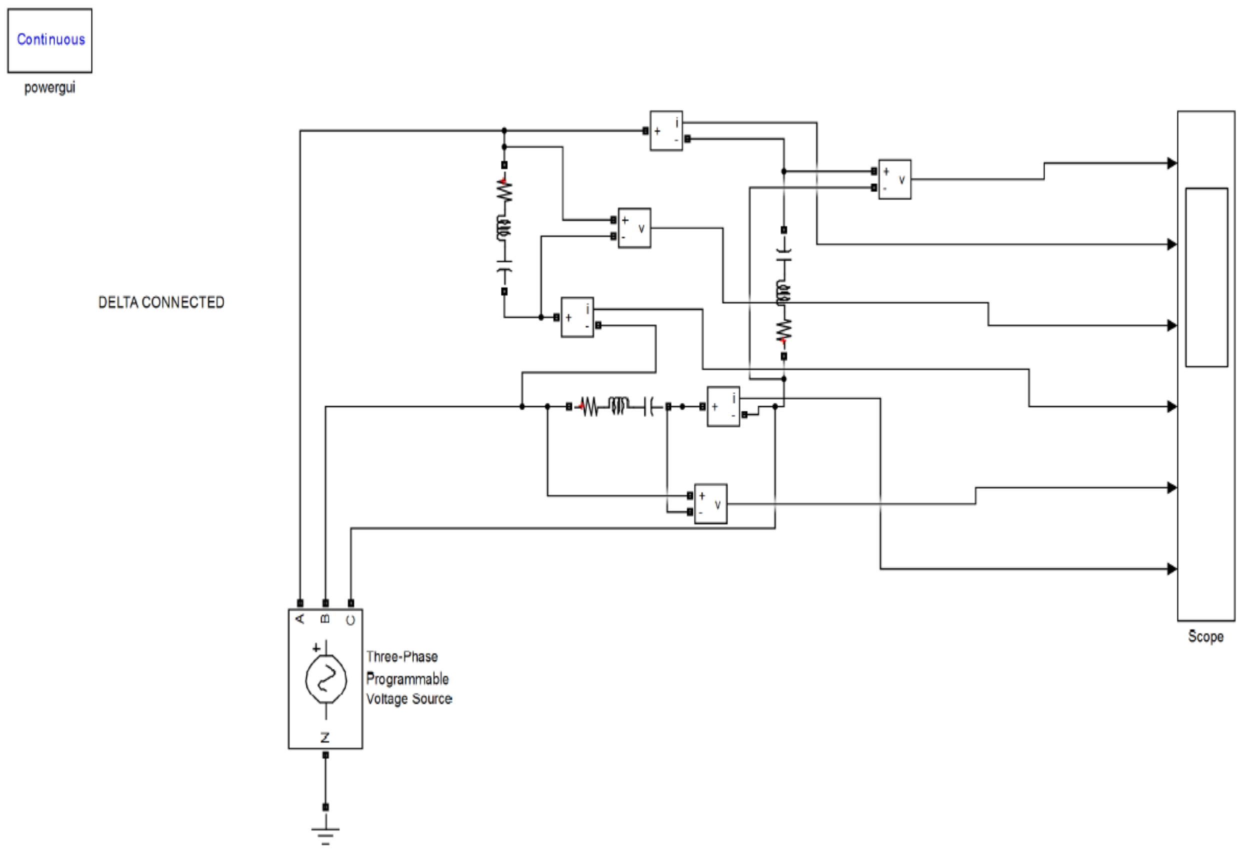


Fig 3. Delta connected system.

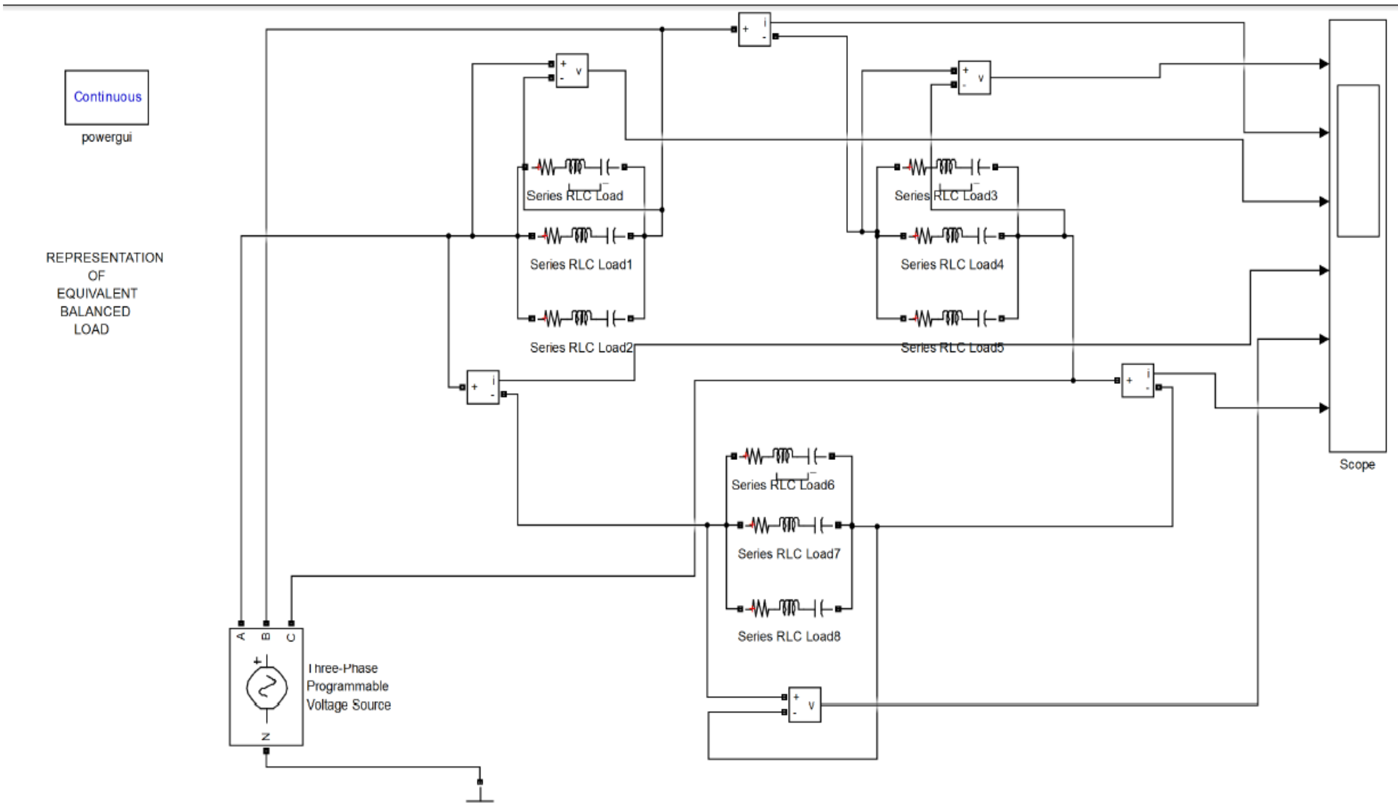


Figure 4. Representation of equivalent balanced load.

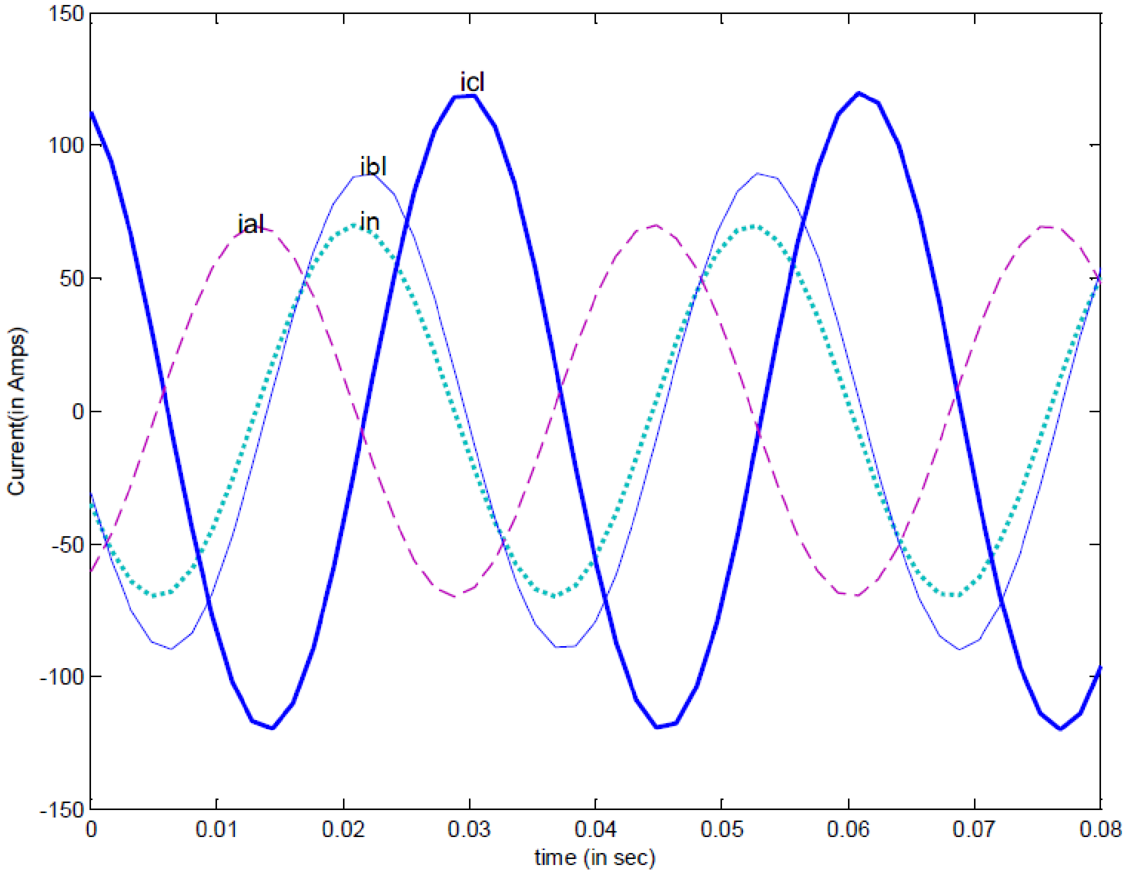
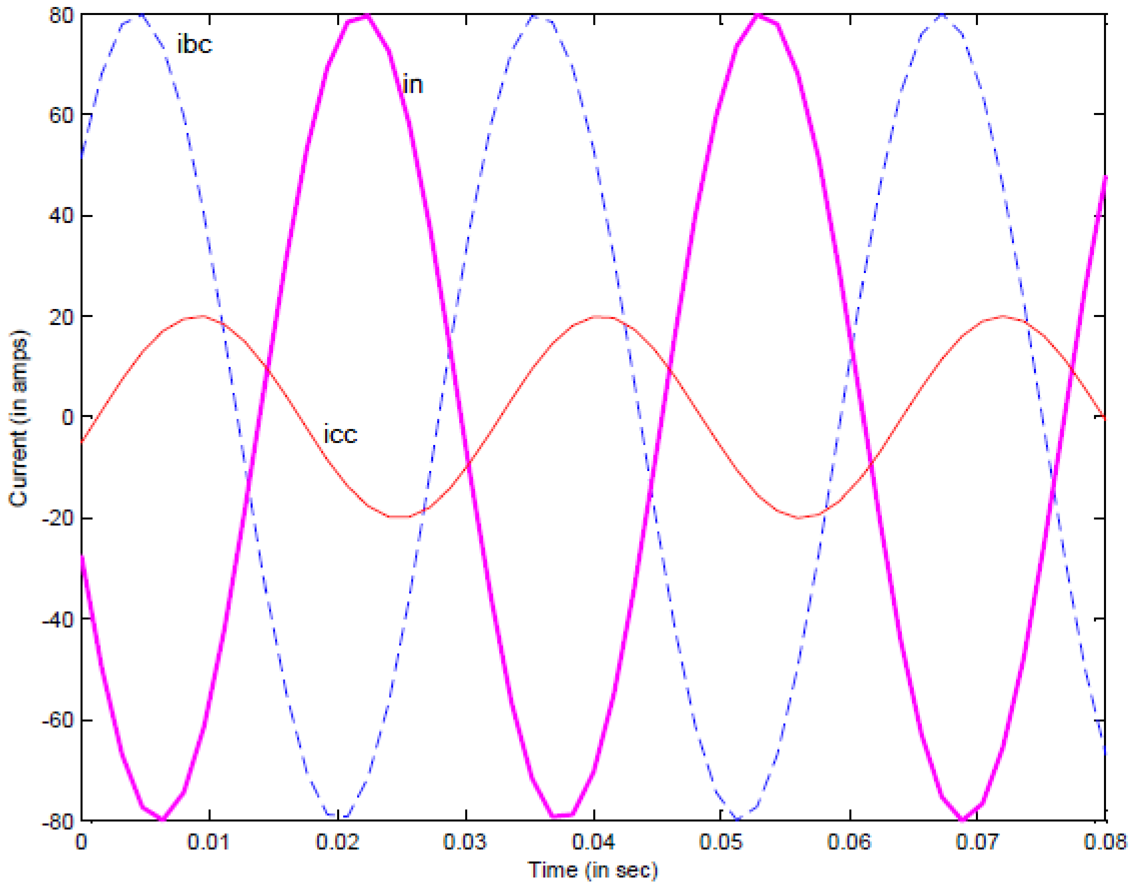


Figure 5. Load currents ial, ibl and icl and neutral current in.



Neutral Current Compensation in first scheme. Ibc and Icc are load currents through phase b and c. In is the neutral current.

Fig 6. Neutral Current Compensation in first scheme. ibc and icc are load currents through phase b and phase c. In is the neutral current.

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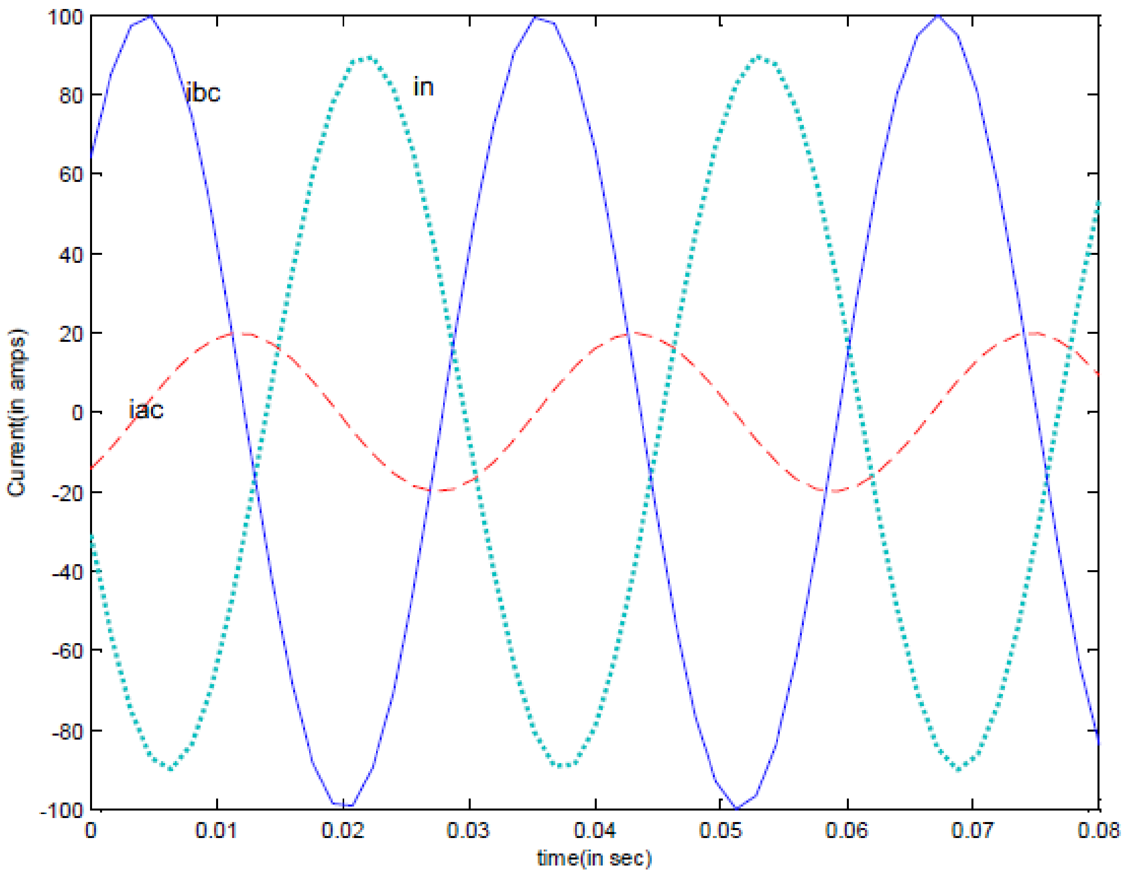
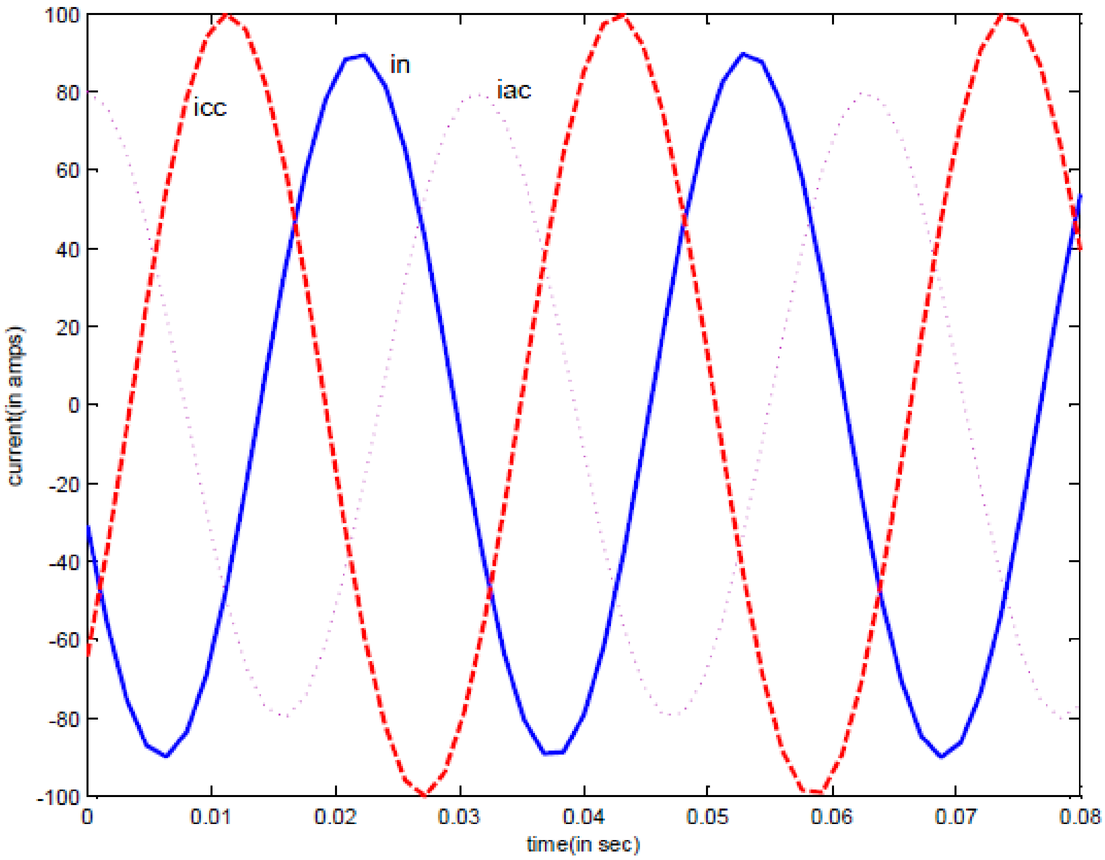


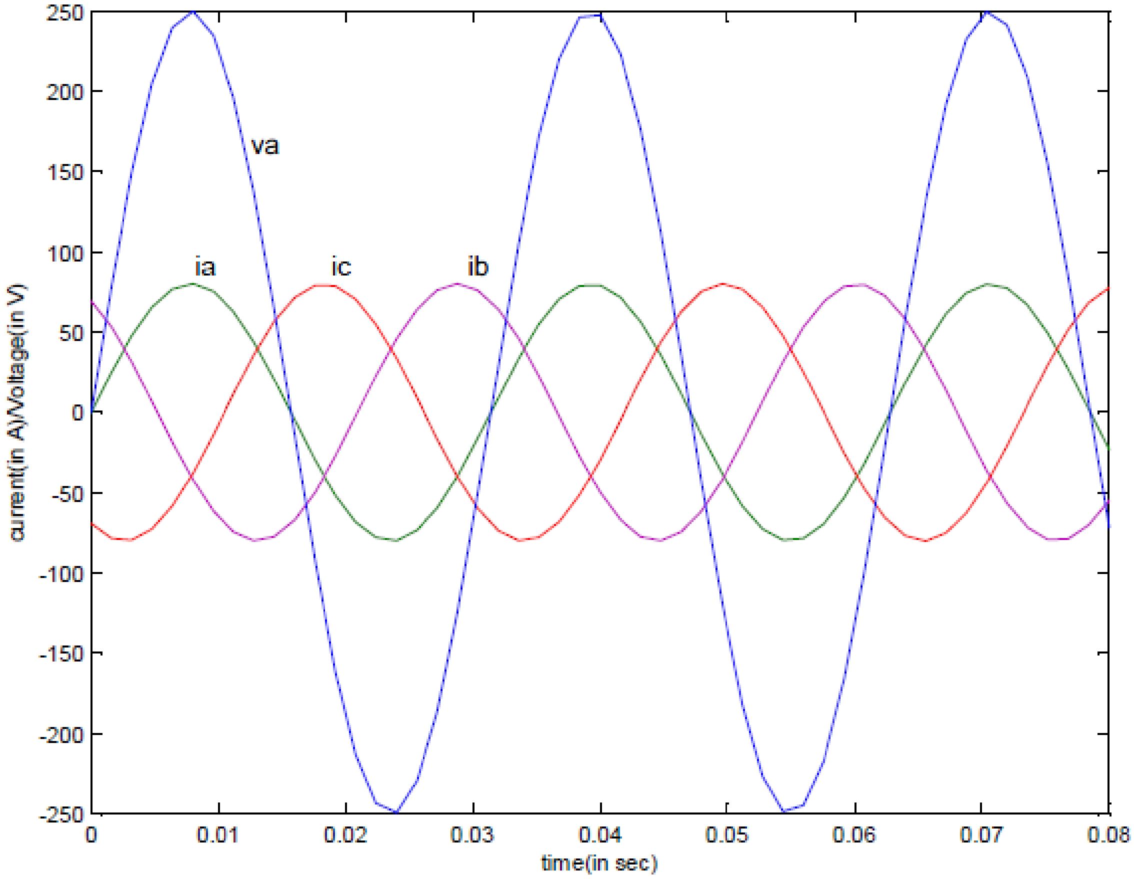
Neutral current compensation by second scheme. Iac and Ibc are the load currents through phase a and b.

Fig 7. Neutral current compensation by second scheme. iac and ibc are the load currents through phase a and b.



Neutral current compensation by third scheme. Iac and Icc are the load currents through phase a and c.

Fig 8. Neutral current compensation by third scheme.



Supply voltage Va and three balanced supply currents through phases a, b and c.

Fig 9. Supply voltage and balanced supply currents through phase a, b, c.

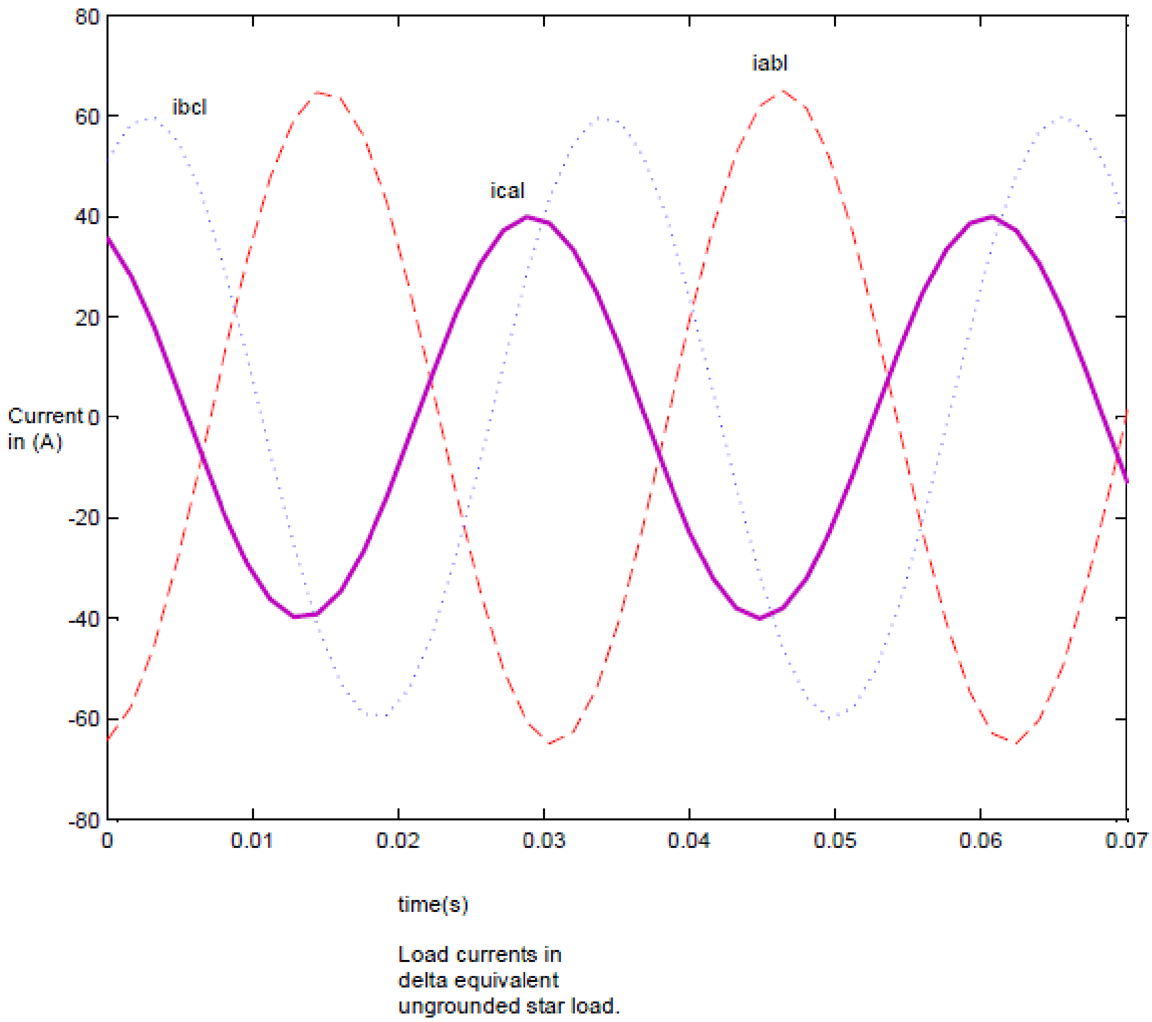


Fig 10.Load currents in delta equivalent ungrounded star connected load.

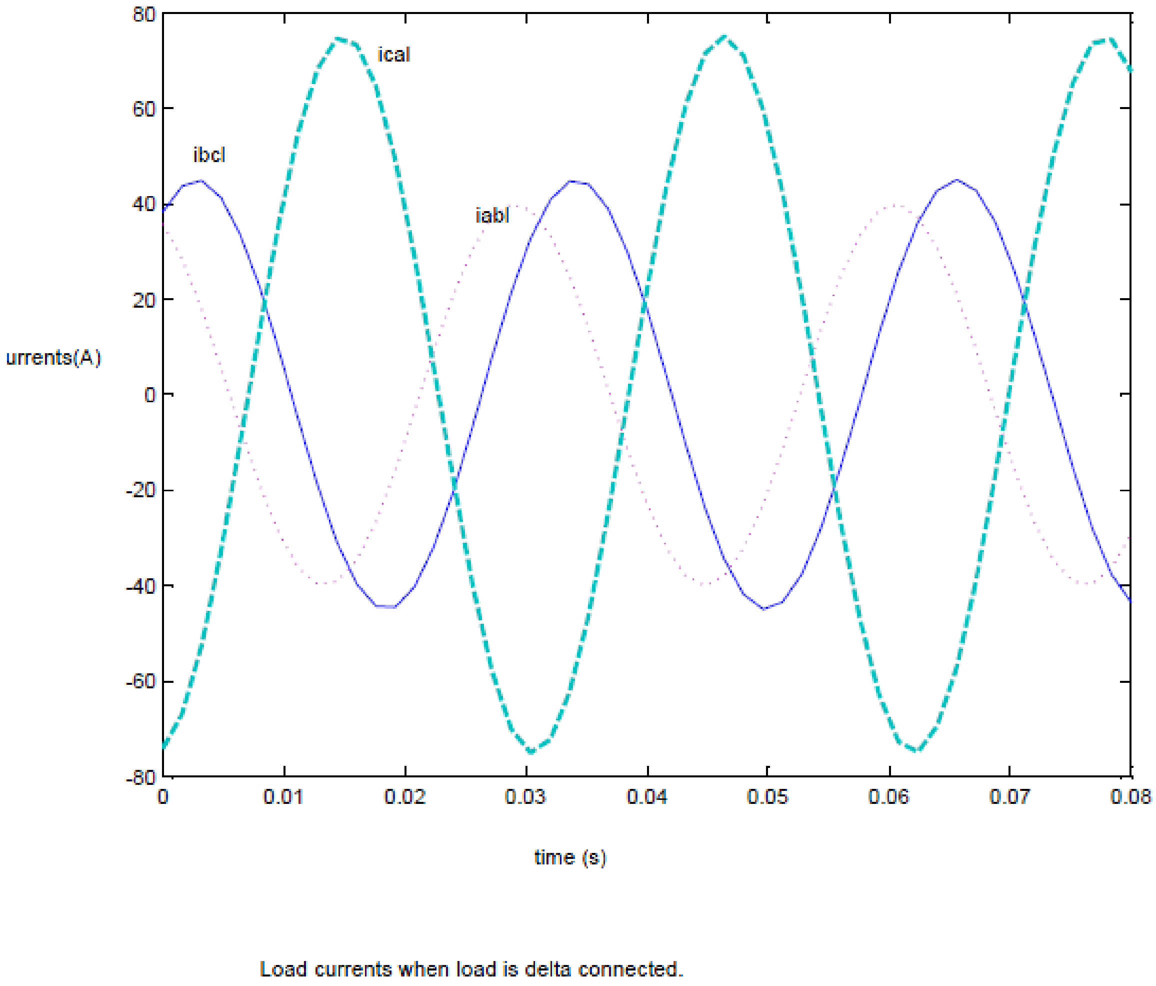


Fig 11. Load currents when load is delta connected.

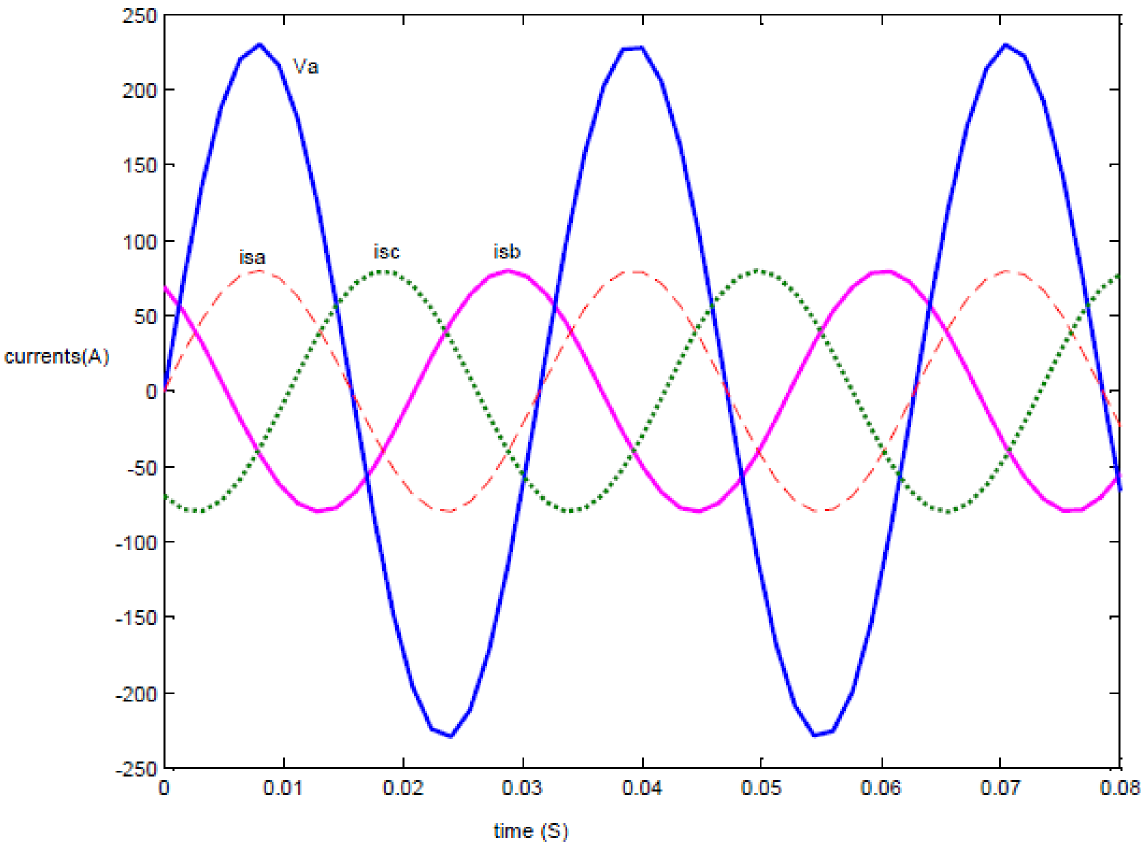


Fig 12. Balanced supply currents and voltage through phase a, b, and c.

CONCLUSION

The star connected grounded load, after neutral current compensation becomes equivalent to ungrounded star connected load. By putting the corresponding susceptances, the neutral current becomes almost equal to zero. The future work includes power factor and load balancing of the ungrounded load. The star connected load is transformed to delta connection and the corresponding susceptances are determined.

We proposed three schemes for neutral current compensation. We obtained a system without any neutral current. The system is now an ungrounded system. We carry out star delta transformations to convert it into equivalent delta connected load. After that we carry out the power factor correction and load balancing scheme.

REFERENCES

[1] Arindam Gosh, Senior Member, IEEE, and Avinash Joshi " A New Approach to Load Balancing and Power Factor Correction in Power Distribution System", IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 15, NO. 1, JANUARY 2000.

[2]C.L Wadhwa, "ELECTRICAL POWER SYSTEMS ", New Age International Publishers 2011.

[3]A.Kern and G.Schroder, "A novell approach to power factor control and balancing problems",Proc. Of Conf. IEEE-IECON Record, pp 428 433,1994.

[4]M.Z.ElSadek,"Balancing of unbalanced loads using static var compensator", Electrical Power System, vol. 12, pp137-148-1987.

[5]C. Schauder and H.Mehta, "Vector analysis and control of adVaced static var compensators for loss reduction in radial distribution feeders", IEEE Transaction on Power Delivery, vol.6, no.4, pp1848-1855,1991.