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Instantaneous Reactive Power Control for Electric Traction to Compensate Harmonics for Linear and Non Linear Loads by Using V-V or Scott Connection Transformers

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1. Introduction

Control strategies are simulated using a state variable model representation and experimentally validated using a DSP based modular power electronic system able to emulate electric traction system operating conditions, the open delta and Scott transformer connection schemes, the filtering and the load balancing power converters .The power range for the railroad application in this paper is around 10 MVA, and its implementation using multilevel converters have several advantages. Multilevel converters continue to be a topic of intense research and there are several modulation techniques, reported in the literature, with several advantages over conventional two-level converters. An important advantage of multilevel converters is the possibility to improve harmonic content of the synthesized voltage with a reduced amount of commutation. Another advantage of multilevel converters is the possibility to reach higher voltage levels and higher power ratings with power devices having lower breakdown Voltages.

The increase in components in multilevel converters results in a corresponding increase in the number of valid commutation states, and thus in smoother changes in the state variables of the system and its consequent reduction in*dv/dt* of the output voltage. Among many existing multilevel topologies, the dual converter has the advantage that two standard two-level converters can produce multilevel operation. However, the main disadvantage of the dual-converter topology is the need for a coupling transformer, not needed in other multilevel topologies for the same range of power and voltage.

The generality of the proposed filtering technique using instantaneous active and reactive power can be applied to any transformer configuration scheme in the power substation. Multilevel converter technology can facilitate the industrial implementation because it reduces the specifications of the power electronics switches and the voltage stress *dv/dt* on the magnetic components like coupling transformers and/or inductors. These problems are usually addressed, in practice, with the use of passive power quality compensators such as reactive power compensation capacitors and passive filters, and they are single-phase equipment installed in each feeder from the traction substation. Usually, the coupling factor between two feeders is negligible due to the independent operation of each passive compensator. Moreover, passive equipment does not have the dynamic capability to adjust to changes in load, where over and under compensation happen frequently as a result of Continuous changes in load conditions.

There are different active power quality compensators proposed in the literature, to solve the unbalance problem, but they neglect the sequence components introduced by harmonics. Also, all of them employ two single-phase converters that have a common dc bus, but they cannot provide simultaneous compensation of unbalance and harmonic content. However, for the compensation made from the three-

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phase side, the use of the instantaneous active and reactive power definition provides a way for simultaneous compensation of unbalance and harmonics. The traction system under study is similar to the stage 1railway in Venezuela. It draws power using a Scott transformer (115/25 kV, 60 Hz, 40 MVA).

This transformer provides two single-phase lines with a 90◦phase shift between them. One of the single-phase lines feeds both ways of the Charallave–Caracas section (24 km), with a ramp of 3.125%.The other single-phase line feeds both ways of section (17.5 km), with less traffic and a ramp of 0.6%, resulting in fewer loads for this phase. For this configuration, the Scott transformer has an unbalance in the range of 12–20%in normal operation, and 40% for emergency operation. The railway system uses eight four-wagon trains, with half of the wagons powered. Each powered wagon has four 600 kW induction machines fed with DTC controlled VSCs and single-phase PWM in the rectifier front end.

2.1. Harmonic and unbalance compensation system

On balanced three-phase systems feeding balanced linear loads, the instantaneous active and reactive terms of the complex power are constant and equal to$p(t)$ = 3VI cos(φ) and $q(t)$ = 3VI sin(φ) , whereas for similar balanced three-phase systems, the instantaneous active and reactive power with unbalanced nonlinear loads contains average and oscillating terms. To compensate for load imbalance and reduce harmonic injection from the load to the supply system, the proposed controller is aimed at keeping constant the instantaneous active and reactive power exchange with the supply. In this paper, this is achieved with a shunt active filter directly connected to the power system using a voltage step-up filter transformer. For the railway application, the power stage in the filter is a three-phase voltage source converter (VSC) with a rating between 10% and 15% of the distribution transformer rated power. The controller computes the total instantaneous active and reactive power taken by the combination of traction

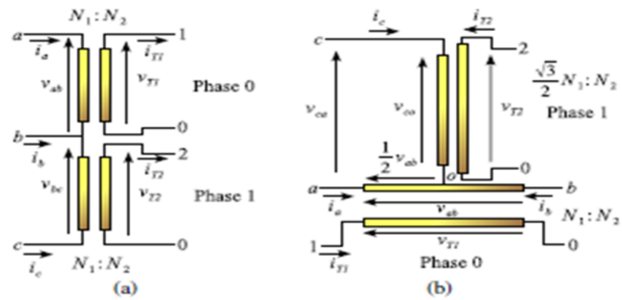

Fig. 1 Traction transformer schemes. (a) V-V transformer. (b) Scott transformer

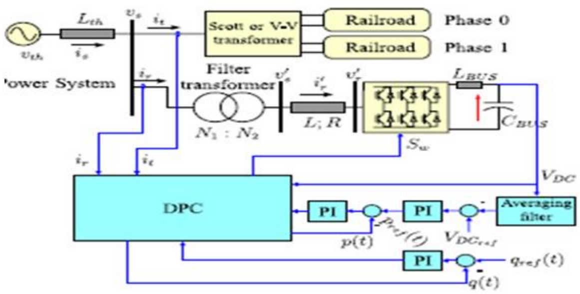

Fig 2. Proposed compensation scheme

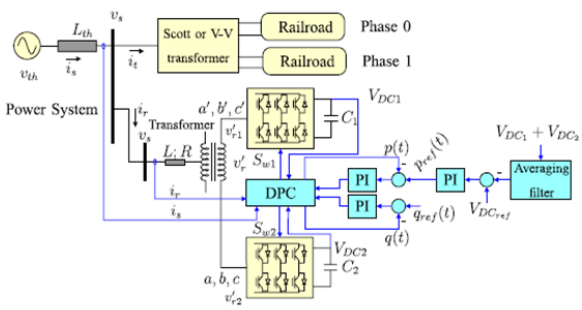

Fig 3. Proposed compensation scheme

Proposed algorithm has low computational demands, provides instantaneous correction of the active and reactive power in the point of common coupling, and reduces the ripple in the instantaneous power and currents. This produces low harmonic distortion and balances the load seen from the grid.

3.1 Railway Traction

Where the term to the left of the equal sign is the sum of all the forces acting in the Longitudinal direction of the train, “M” is the total mass and “a” is the longitudinal Acceleration experienced by the train. The sum of forces consists of the tractive or braking effort

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“Ft” and the passive resistances opposing the forward motion of the train, “ΣFR”, The tractive or braking effort “Ft”, in a final instance, is the resultant of the longitudinal adhesion forces that appear in the wheel-rail contact zones, either when the train’s motors make the wheels rotate in the direction of forward motion, or when the braking forces act to stop the wheels rotating (in this case, these forces will obviously be negative or counter to the direction of the train’s forward motion.

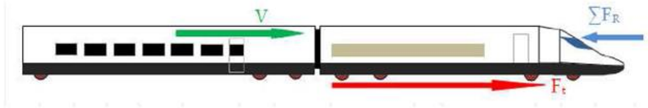

Fig 4 represents longitudinal train dynamics

$$\sum F_R = (266{,}3+27{,}7\cdot V+0{,}05168\cdot V^2)+(r_g+\frac{500}{R})\cdot(L+Q)$$

Where “V” is the train’s speed in (Km/h), “rg” is the inclination of the gradient as a (o/oo),“R” is the radius of the curve in (m), “L” is the weight of the locomotives in (Tm) and “Q” is the towed weight or the weight of the coaches in (Tm).

The resistances to forward motion consist of three components: one constant, another that is linearly dependent on speed and another that depends on the speed squared. Moreover, when the train is running on a curve or a gradient, the final term that is not dependent on speed needs to be added. We will now develop the Bond-Graph model, for the longitudinal train dynamics expressed in equation .In this model, shown in Figure, there are three basic elements. The most important element is the train itself, whose longitudinal motion is represented by the Inertial port “I”. The parameter of this port is the train’s total mass, “M”. b. The tractive or braking efforts “Ft”. In whatever case, this is an element that supplies energy according to a defined force. In Bond-Graphs, these energy sources with a Fig. Longitudinal train dynamics.

Let us now focus on the passive resistances that are opposing the train’s forward motion, “ΣFR”. These basically consist of five types of forces:

a. Rolling resistances of the wheels.

b. Friction between the contacting mechanical elements.

c. Aerodynamic resistances to the train’s forward motion.

d. Resistances to the train’s forward motion on gradients.

e. Resistances to the train’s forward motion on curves.

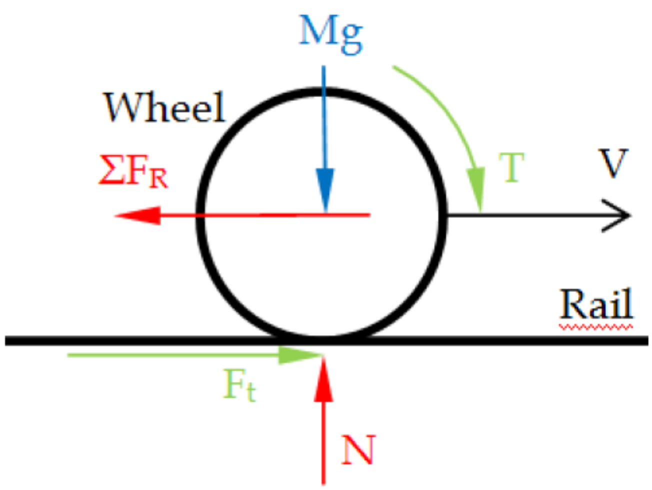

Fig 5 represents Tangential adhesion forces in the wheel-rail contact

Right from the beginnings of the railway the major challenge of railway traction has been to Increase the adhesion coefficient in the wheel-rail contact. Fig shows some of the adhesion coefficient values “μo”, used. What is surprising is the high value achieved for this coefficient in the United States of America. Some of the methods used to improve the values of the adhesion coefficient, especially during start up or acceleration, for reasons which will be made clear further on, are: a. Introduction of sand in the wheel-rail contact. This is the traditional method using devices called “*sandboxes*”, which are still frequently in use. However, this is a very aggressive system regarding the wear of wheel and rail materials. Monometer bogies that spread the tractive efforts evenly between all their shafts lead to an optimization of the adhesion coefficient used. Drawbars that connect the

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locomotive chassis to the bogies in a way that the locomotive's weight falls on the lowest part of the bogie at a level that is as close as possible to the wheel-rail contact. Apparently, the accelerations between the locomotive chassis and the bogie generate a force torque that aids the tractive or braking efforts, thus improving wheel-rail adhesion. Electronic anti-slip, braking and traction control systems. These are similar systems to ABS, (Anti-lock Braking System), or ASR, (Anti-Slip Regulation) used in the automotive industry. The speed of the wheels is controlled and regulated by electronic devices so that there is no slip between the wheels and the rails.

In traction, the ideal situation is to have the maximum effort according to speed. As we know, the power developed is the product of force and speed: Since the power supplied by the motor is approximately constant, the tractive effort available "Ft", dependent on the train's speed "V", complies with a hyperbolic-type ratio, like that shown in Figure.

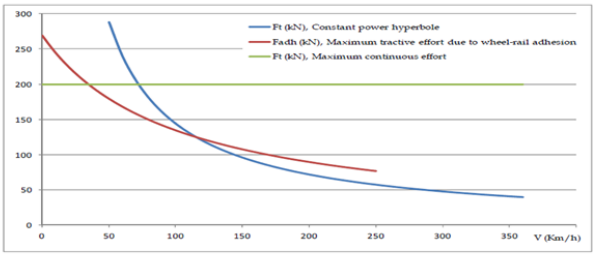

Fig 6. Effort-speed curves

3.2. Railway motors

The first railways were powered by steam engines. Although the first electric railway motor came on the scene halfway through the 19th century, the high infrastructure costs meant that its use was very limited. The first Diesel engines for railway usage were not developed until halfway through the 20th century. The evolution of electric motors for railways and the development of electrification from the middle of the 20th century meant that this kind of motor was suitable for railways. Nowadays, practically all commercial locomotives are powered by electric motors. Figure illustrates a flow diagram for the different types of rail engines and motors most widely used throughout their history. The first Diesel locomotives with a mechanical or hydraulic drive immediately gave way to Diesel locomotives with electrical transmission. These locomotives are really hybrids equipped with a Diesel engine that supply Mechanical energy to a generator, which, in turn, supplies the electrical energy to power the electric motors that actually move the drive shafts. Although this may appear to be a contradiction in terms, it actually leads to a better regulation of the motors and greater overall energy efficiency.

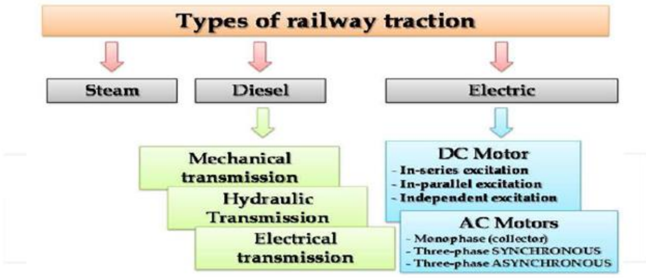

Fig 7. represents railway engine and motor types

The major drawback of electrical traction is the high cost of the infrastructure required to carry the electrical energy to the point of usage. This requires constructing long electrical supply lines called *"catenary"*, (Figure). In addition, the locomotives need devices that enable the motor to be connected to the catenary: the most common being "pantographs" or the so-called "floaters". In its favor, electrical traction can be said to be clean, respectful of the environment and efficient, as an optimum regulation of the motors can be achieved.

In this work, we will only focus on the functioning and regulation of the most widely used types of electric motors.

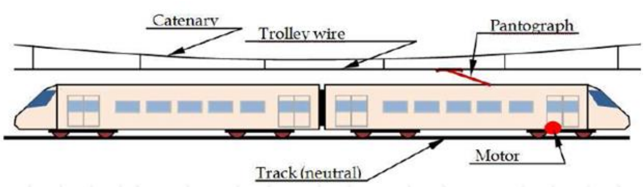

Fig. 8. Electric railway traction: General outline, catenary and pantograph.

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3.3 Electric railway motors

The most widely used electric motors for railway traction are currently of three basic types,

1. Direct current electric motors with in-series excitation.

2. Direct current electric motors with independent excitation.

3. Alternating current electric motors.

Direct current electric motors usually work under a 3 kV supply and alternating current motors under 25 kV. Direct current motors are gradually becoming obsolescent in favor of alternating current motors. This is mainly due to maintenance problems with the direct current motor collectors and the better technological progress of alternating current motors. This work does not aim to provide an exhaustive development of the behavior of electric motors. It will only make a compilation of the equations and behavior models of electric motors that have already been published and accepted, particularly those that apply the Bond-Graph Technique, Direct current electric motors (hereafter DC), are mainly made up of two components: a stator or armature and a rotor or armature. The stator's mission is to generate an electric field at the core of which the rotor is inserted. This magnetic field of the stator is generated by windings through which an electric current is made to flow. An electric current is also made to flow in the rotor. As this is immersed in a magnetic field generated by the stator, the electric current conductor undergoes mechanical forces that cause the rotor to rotate on its shaft. The outline shown in Figure 8 corresponds to the so-called *DC motors with independent excitation*, as the operating voltage of the stator and the rotor is independent. Also, the windings of the stator and the rotor can be interconnected giving rise to two other types of DC motors:

a. DC motors with in-series excitation, if the windings of the stator and rotor are connected in series.

b. DC motors with in-parallel excitation, when the windings of the stator and rotor are connected in parallel under the same operating voltage. Firstly, we will deal with the modeling of DC motors with independent excitation and then go on to DC motors with in-series excitation, making some slight adaptations.

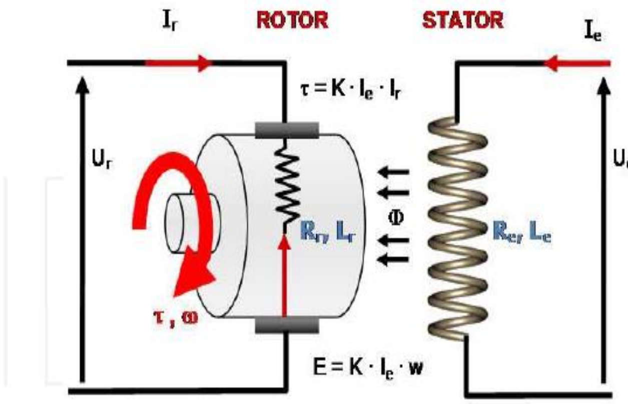

Fig. 9. Electromechanical circuit diagram of a DC electric motor.

3.4 .Electric motors with independent excitation

As already indicated, Figure 9 illustrates the electromechanical outline of a DC motor with independent excitation. Figure 9 represents the same model in a Bond-Graph using the Sources of Effort "SE", with ratios "Ue" for the stator and "Ur" for the rotor. The electric Reliability and 12 Safety in Railway current voltage "Ue", is used to overcome the ohmic resistances "Re" in the stator circuit and To generate a magnetic field "Φ" in the winding. The ohmic resistances are represented by the Resistance port "R" with parameter "Re". The behavior of the winding is frequently represented by an inertial port. However, in this case, in order to be able to consider the magnetic losses produced in the air-gap and in the gap between the stator and the rotor, the electrical energy reaching the winding is firstly converted into magnetic energy. The equations governing the transformation of electrical energy into magnetic energy in the stator winding are:

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4. Popular distribution transformer and distribution circuits voltages

4.1. 2400-volt systems and transformers

In any particular voltage class, the actual rated voltage of a transformer has increased in years past. For example, the 2400-volt class of transformers formerly were rated 2200-110/220, then later they were rated 2300 115/230 and today they are rated 2400-120/240 volts. This gradual increase in the rated voltage of transformers also occurred in the other voltage classes. Throughout the following material, we will speak of a particular voltage class by using present day rated voltage terminology. In the early days of urban-electrical distribution, practically all systems were 2400-volt class, delta systems, and the 2400-volt transformer was designed and manufactured for this system. The selection of 2400 volt for distribution was logical from the standpoint of service and economy. This voltage is high enough to give good system performance on systems where the distribution circuits are not very long. In addition, the voltage is sufficiently low to result in economical distribution equipment. In recent years most 2400-volt delta systems have been changed over to 2400/4160Y-volt systems. This change was due to the fact that as the 2400-volt delta systems became more heavily loaded it became necessary to put in larger distribution-line conductors or raise the operating voltage in order to maintain proper voltage regulation. The most economical procedure in this case was to raise the operating voltage to 4160Y, and this was economical because the change did not necessitate a change in transformers or other equipment on the line. 2400/4160-volt distribution systems are used in most urban areas throughout the country. Another factor that has contributed to the change from delta to Y systems

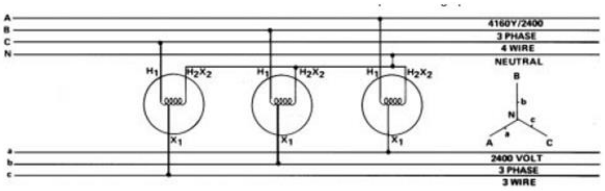

Fig.10. Represents three-phase delta banks connected to 2400/4160Y-volt systems

4.2. Voltages and Connections 4160-volt transformers

The 4160-volt transformer came about through the 4160Y-volt connection on 2400-volt transformers. In some cases, it was advantageous to connect transformers between phase wires on a 2400/4160Y-volt system, and this required a transformer having a winding voltage of 4160 volts. These 4160-volt transformers are now used in several ways. First, they are used in three-phase delta banks connected to 2400/4160Y-volt systems. Another application is for a 4160-volt single-phase line taken off of a 2400/4160Y-volt three-phase system. On this single-phase line, it is necessary to use 4160-volt transformers. In recent years, rural electrification has expanded greatly, and in some cases, the 4160-volt line of transformers is used for rural systems rated 4160/7200Y. With this system, 4160-volt transformers can be used between phase wire and neutral of a three-phase four-wire system, and 7200-volt transformers can be used between phase wires.

4.3 .4800 Volt systems and transformers

The 4800-volt line of transformers is quite popular in some sections of the United States where distribution circuits run through thickly populated rural and suburban areas. Distribution lines in these localities are necessarily much longer than in cities, and therefore, the 2400- volt system is not high enough voltage to be economical. 4800-volt distribution in these areas has proved to be quite logical and satisfactory. Here again, the systems originally were 4800-volt delta, three-phase systems with 4800-volt, single-phase branch lines.

These delta systems have now been changed in some cases to 4800/8320Y giving a higher system voltage but using the same equipment that was used on 4800-volt delta systems. This change came about due to increased load on the line, and this change is quite similar to the change that took place in the 2400-volt delta system.

4.4 .7200 Volt systems and transformers

Rural electrification in thinly populated areas required still higher voltage for good performance and economy. Therefore, for rural electrification in the mid-west, south, southwest and western sections of the United States, 7200-volt distribution systems have been used quite extensively and successfully. The early rural systems were 7200-volt delta, three-phase in most cases, with 7200-volt single-phase branch lines. These systems have now given way to 7200/12,470Y-volt three-phase four wire systems. This change became necessary due to the fact that existing 7200-volt delta, three-phase lines became more heavily loaded and also due to the fact that rural lines have been extended to much greater length than formerly. For strictly rural electrification in the sections of the country mentioned above, the 200/12,470Y-volt three phase four-wire systems is by far the most popular today. 7200-volt single-phase branch lines are run for considerable distances from the three-phase four-wire main lines. On these single-phase branch lines, the so-called single-bushing rural transformer has been used. This is a line of 7200-volt, single-phase transformers with only one high-voltage bushing mounted on the cover, and the other side of the high-voltage winding is permanently connected to the tank. This type of rural transformer is a part of rural-distribution construction designed for economy.

Most of the single-phase rural lines today have one hot wire carried on an insulator on top of the pole and one ground wire carried on the side of the pole at some distance from the top. The 7200-volt rural transformer is mounted directly to the pole with through-bolts, thus eliminating crossarms, crossarm braces, etc. Connection is made between the high voltage bushing and the hot wire on top of the pole, and the tank is connected to the ground wire carried on the side of the pole. This type of rural distribution system is much more economical than the type that was used some years ago, and as a result, it is now economical to serve many more rural customers than in previous years.

4.5. 7620- Volt systems and transformers

7620-volt line of transformers is also used for rural electrification but this voltage is less popular than the 7200- volt class. Some 7620-volt delta three-phase systems have been used but practically all 7620-volt systems now are 7620/13,200Y-three-phase four-wire systems. on this system, 7620-volt single-phase transformers can be used between phase wire and neutral of the threephase four-wire system or 13,200-volt transformers can be used between phase wires. The 7620/13,200Y-volt distribution system works out very economically for companies that have both 7620- and 13,200-volt distribution, In this situation, transformers can be used on either system, thereby making stocks of transformers flexible.

4.6. 12,000- Volt systems and transformers

There are some 12,000-volt three-phase delta systems that were built some time ago for transmission and power over greater distances than were feasible in lower voltages. There are now two applications for 12,000-volt transformers. The first is for use on 12,000-volt delta three-phase systems and second, for use on 7200/12,470Y-volt systems. 12,000-volt transformer can be used between phase wires on the 7200/12,470Y-volt three-phase four-wire systems and such use is fairly common today.

4.7. 13,200- Volt systems and transformers

The 13,200-volt transformer also has two applications. First, for use on distribution systems that is 13,200-volt delta three-phase which were built to distribute electrical energy at considerable distance. The second application has already been mentioned in connection with the 7620/13,200Y-volt three-phase four-wire system. On this system, the 13,200-volt standard transformer can be used between phase wires of the three-phase four-wire system. This connection is made quite often when it is necessary to connect a three-phase bank of transformers to the 7620/13,200Y-volt three-phase four-wire systems.

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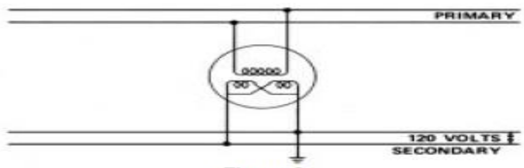
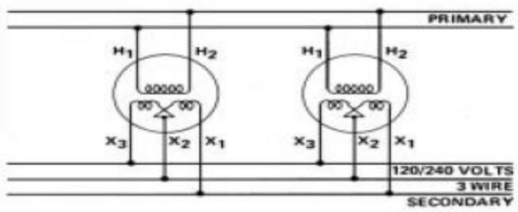
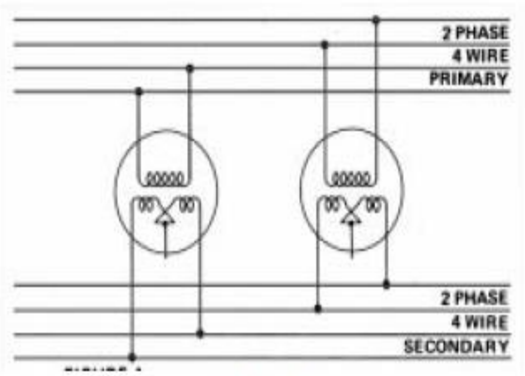
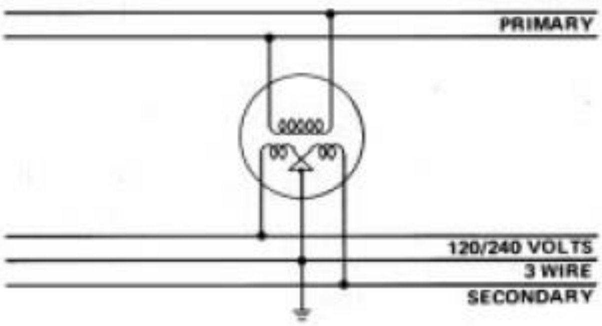


Figure 3



Transformer is placed between high-voltage line and low voltage. The 120/240-volt low-voltage windings are connected in parallel. This type of connection would be used to supply one customer with 120 volts for lights.





For Power This connection is similar to single phase for lights except 120/240-volt low-voltage windings are hooked in series giving 240 volts on a two-wire system as shown

For Light and Power

This connection is the most common for city distribution. The three-wire system makes it possible to serve both 120 volt and 240 volt loads simultaneously.

4.8. Hooked in Parallel

Two single phase transformers can be used in parallel on a single-phase three-wire system if the terminals with the same relative polarity are connected together. This is not a very economical operation because the individual cost and losses of the smaller transformers are greater than one larger unit giving the same output. This is mentioned as emergency operation for small transformers. In larger transformers, however, it is many times practical to operate units in parallel as a regular practice. A two-phase system is simply two single-phase circuits operated 90° out of phase with each other. In Figure 7 they may be treated as two separate circuits. In Figure 8, however, there is a common wire on the secondary side resulting in some saving in copper. The common wire must carry 1.41 X current in other secondary wire if subtractive-polarity transformers are used in three phase banks secondary connections are simplified from those shown for the additive-polarity units. The additive polarity connections, for standard angular displacement, are somewhat complicated, particularly in cases with delta-connected secondary, by the crossed secondary interconnections between units. For this reason simplified bank connections, which give non-standard angular displacement between primary and secondary systems are sometimes used with additive-polarity units.

Standard Angular Displacement

Standard angular displacement or vector relationships between the primary and secondary voltage systems, as defined by ANSI publications, are 0° for delta-delta or wye-wye connected banks and 30° for delta-wye or wye-delta banks. Angular displacement becomes important when two or more three-phase banks are

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interconnected into the same secondary system or when three-phase banks are paralleled. In such cases it is necessary that all of the three-phase banks have the same displacement.
The following diagrams cover three-phase circuits using:

1. Standard connections—where all units have additive polarity and give standard angular displacement or vector relation between the primary and secondary voltage systems (as defined by ANSI publications).

2. Simplified connections for the more common three phase connections with the delta-connected secondary— where all units have additive polarity but give nonstandard angular displacement between the primary and secondary voltage system.

4.9. Polarity Effects

Any combination of additive and subtractive units can be connected in three-phase banks so long as the correct polarity relationship of terminals is observed. Whether a transformer is additive or subtractive does not alter the designation of the terminals (X1, X2, etc.) thus correct polarity will be assured if connections are made as indicated in the diagrams. The terminal designations, if not marked, can be obtained from the transformer nameplate which shows the schematic internal-connection diagrams diagramming the actual physical relationship between the high and low voltage terminals.

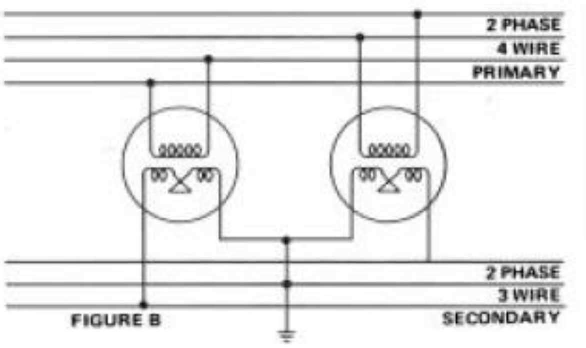

Fig.11. represents a two-phase system is simply two single-phase circuits

Operated 90° out of phase with each other

Standard Connection This type of three-phase transformation has been the one most commonly used in the past. The ungrounded primary system will continue to supply power even though one of the lines is grounded due to a fault.

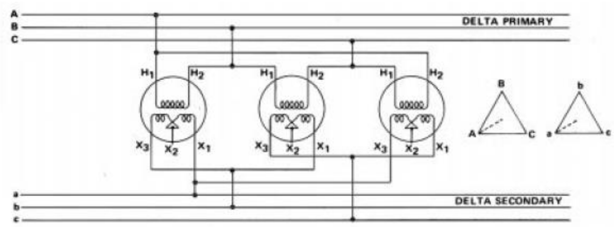

Fig .12. Represents Delta-Delta for Power

Simplified Connection This is similar to the connection above but gives a 180° angular displacement which is non-standard. Otherwise the information given above is applicable to the connection.

Standard Connection

When light and power are to be supplied from the same bank of transformers, the mid-tap of the secondary of one of the transformers is grounded and connected to the fourth wire of the three-phase secondary system as shown in the diagram. The lighting load is then divided between the two hot wires of this same transformer, the grounded wire being common to both branches.

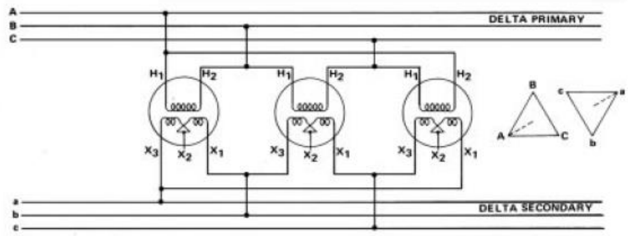

Fig.13. represents Delta-Delta for Power 180 deg out phase

Standard Connection As mentioned before, this connection can be used in an emergency in case one of the transformers in a delta delta bank fails. This type of bank is also used to supply power to a three-phase load which is temporarily light but which is expected to grow. When the load increases to a point where the

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two transformers in the bank are overloaded, an increase in capacity of 1.732 times can be obtained by adding another unit of the same size and using the delta-delta connection.

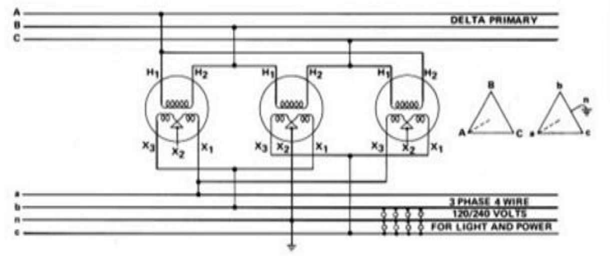

Fig.14. Represents Delta-Delta for Light and Power

Simplified Connection

This is similar to the connection above but gives a 180° angular displacement which is non-standard. Otherwise the information given above is applicable to this connection. The capacity of an open delta bank is only 57.7% of a delta-delta bank of the same size units. That is, three 25 kva transformers connected delta-delta would have a capacity of 75 kva. Two 25 kva transformers in an open delta bank would have a capacity of only 43.2 kva. It is convenient to remember that in an open delta bank only 86.6% of the capacity in the transformers is realized.

Simplified Connection

This is similar to the connection above but gives a 180° angular displacement which is non-standard. Otherwise the information given above is applicable to this connection.

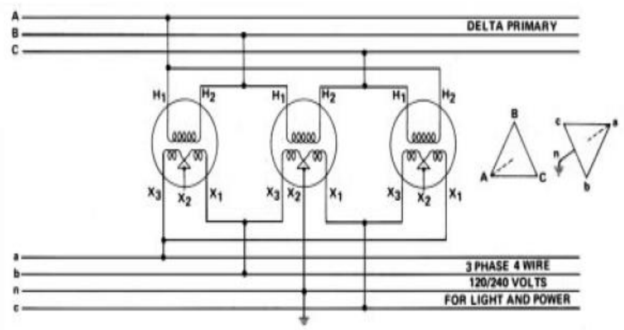

Fig.15. Represents Delta-Delta for Light and Power

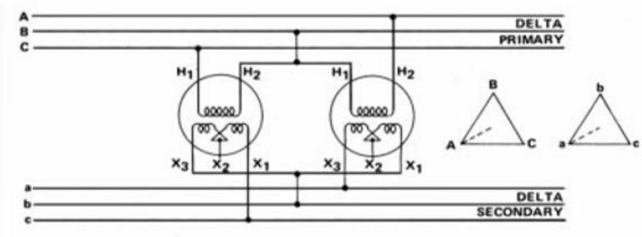

Fig 16. Represents Open Delta for Power

The capacity of an open delta bank is only 57.7% of a delta-delta bank of the same size units. That is, three 25 kva transformers connected delta-delta would have a capacity of 75 kva. Two 25 kva transformers in an open delta bank would have a capacity of only 43.2 kva. It is convenient to remember that in an open delta bank only 86.6% of the capacity in the transformers is realized.

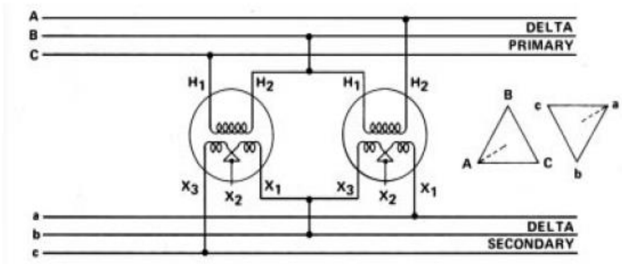

Fig 17. Represents Open Delta for Power

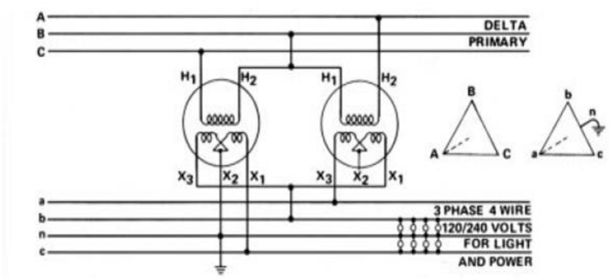

Fig 18. Represents Open Delta for Light and Power

Standard Connection

When the secondary circuits are to supply both light and power, the open-delta bank takes this form. In addition to the applications listed above for the open-delta bank for power, this type of bank is used where there is a large single-phase load and only a small three-phase load. In this case, the two transformers would be of different kva sizes, the one across which

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the lighting load is connected being the larger. This is also the connection that should be used when protected transformers are employed in a three-phase bank supplying both light and power.

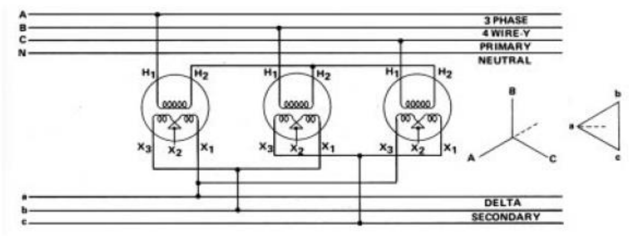

Fig.19 Represents Y-Delta for Power

Standard Connection

The present tendency in utilities is to replace the 2400 delta system with the 2400/4160Y-volt three-phase four wire system. This change in effect raises the distribution voltage from 2400 to 4160 volts without any major changes in connected equipment. The same transformers that were previously connected between lines on the 2400-volt delta system are now connected between lines and neutral on the new 400/4160Y-volt system. Three-phase banks that had previously been connected delta-delta are now connected Y-delta as shown.

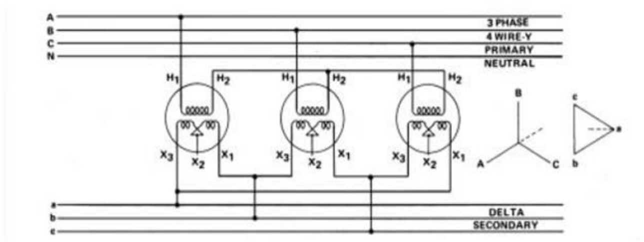

Fig.20 Represents Y-Delta for Power 210 degrees out phase with angular displacement

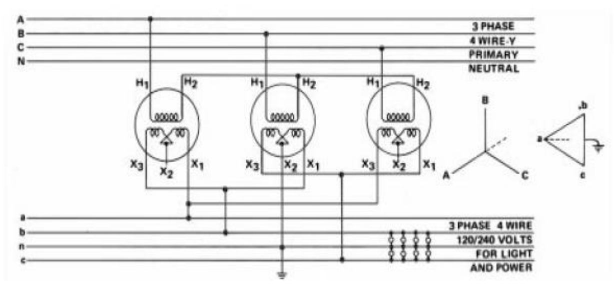

Fig.21 Represents Y-Delta for Power

Standard Connection

When service for both light and power is to be supplied, the Y-delta bank takes this form. Note that the secondary connections are the same as for the delta-delta bank.

Simplified Connection This is similar to the connection above but gives a nonstandard 210° angular displacement. Otherwise the Information contained above is applicable.

Other connections on the delta-delta or wye-wye bank are possible by which an angular displacement of 60°,120°, 240° or 300° can be obtained. In addition, an angular displacement of 90°, 150°, 270, or 330° can be obtained on a wye-delta or delta-wye bank. These connections are not popular and hence are not discussed demonstrated here

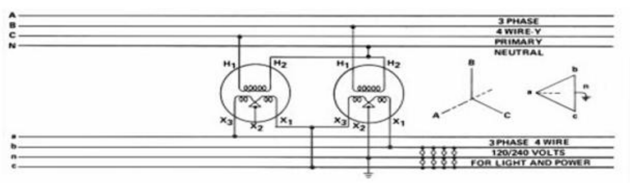

Fig 22. Represents Y-Delta With One Unit Missing

If one unit of a Y-delta bank goes badly, service can be maintained by means of this connection. In the regular Y- delta bank with three units, the neutral of the primaries of the transformers is not ordinarily tied in with the neutral of the primary system. In fact, this bank can be used even when the primary neutral is not available. In the bank with two units, however, it is necessary to connect to the neutral as shown. The main In all the banks mentioned above in which both power and lighting are served on the secondary, the grounded secondary wire is not the neutral of the three-phase system but rather the mid-point of one leg of the delta. Furthermore, the entire lighting load is put on one phase. The primary currents in any one bank, therefore, are unbalanced. In order to obtain balanced currents at the substation or generator, the transformers supplying the lighting loads are connected to different primary phases in the different Three-phase banks.This

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means that different legs of the delta are grounded in the various three-phase banks. This type of secondary connection can, therefore not be used when the secondary's of different banks

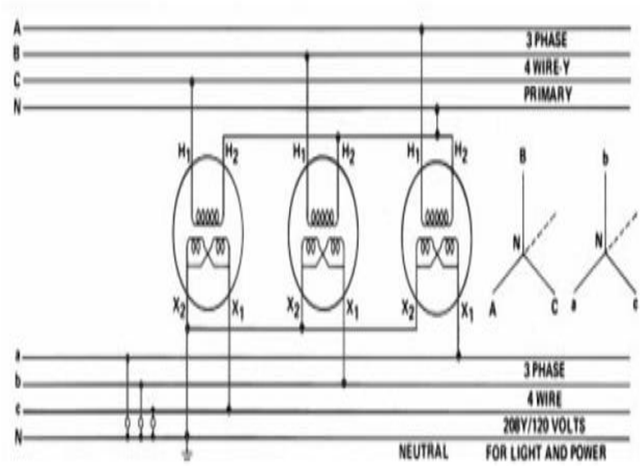

Fig.23.Represents Y-Y for Light and Power

Disadvantage of this hook-up is the fact that full-load current flows in the neutral even though the three-phase load may be balanced. In addition to maintaining service in an emergency, this type of bank is satisfactory where the main part of the load is lighting and the three-phase load is small. This connection is for additive polarity units and gives standard angular displacement are to be paralleled or banked. In regions of high load density, superior operating characteristics are obtained when secondary's are banked. The delta-Y connection is most commonly used when this is done.

Note that standard transformers with 120/240-volt secondary windings are used with the secondary of each unit connected for 120 volts. In this case, the neutral of the secondary three-phase system is grounded. The single-phase loads are connected between different phase wires and neutral while the three-phase power loads are connected to the three-phase wires. Thus, 120 volts is supplied to that the secondary's of different banks can be tied together. This connection is for additive polarity units and gives standard angular displacement

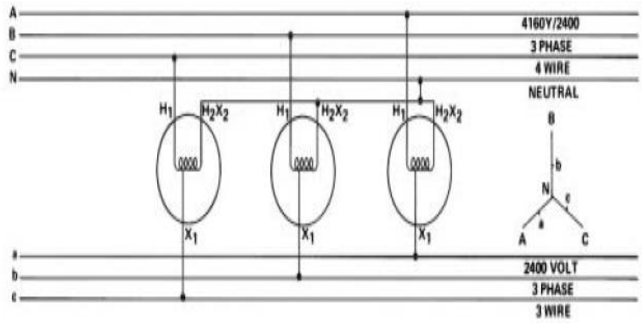

Fig .24. Represents Y-Y Autotransformers for Supplying Power to 2400-Volt Motors from a 2400/4160Y-Volt Three-phase Four-Wire System

The primaries of the transformers can also be connected Y as shown. When the primary system is 2400/4160Y volts, 2400-volt transformers would be used in place of the 4160-volt transformers that would be required for the delta-Y connection. A saving in transformer cost results. It is necessary that the primary neutral be available when this connection is used, and the neutrals of the primary system and of the bank are tied together as shown. If the three-phase load is unbalanced, part of the load current flows in the primary neutral.

Also the third harmonic component of the transformer exciting current flows in the primary neutral. For these reasons, it is very necessary that the neutrals be tied together as shown. If secondary would be very unstable. That is, if the load on one phase were heavier than on the other two, the voltage on this phase would drop excessively and the voltage on the other two phases would rise. Also, large third-harmonic voltages would appear between lines and neutral, both in the transformers and in the secondary system, in addition to the 60-hz component of voltage. This means that for a given value of rms voltage, the peak voltage would be much higher than for a pure 60-hz voltage. This over-stresses the insulation both in the transformers and in all apparatus connected to the secondaries. Figure shows this connection is for additive polarity units and gives the standard angular displacement.

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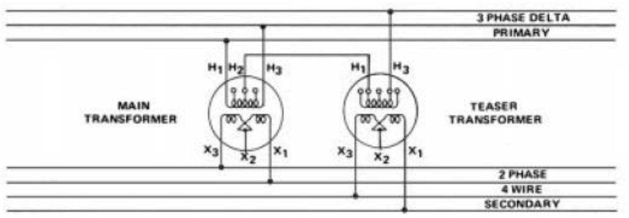

Fig.25. Represents Scott Connection Three-Phase to Two-Phase

Many old distribution systems which originally were two-phase are being changed over to three-phase. Utilities making this changeover are faced with the problem of supplying power to customers having two-phase motors. The Scott bank is most generally used in this connection. The transformers are special in that they have taps at 50% and 86.6% in the primary winding. The currents in the primary windings of these transformers are 15 1/2% greater than when transforming single-phase at the same kva and voltage. This means that a transformer with Scott taps built on the same core as a regular single-phase transformer will have only 86.6% of the kva capacity of the single-phase transformer. For instance, if transformers with Scott taps are built on cores that would normally be used on 50 kva transformers, the kva rating of two of these transformers in a Scott bank would only be 86.6 kva. This connection is for additive polarity units and gives standard angular displacement.

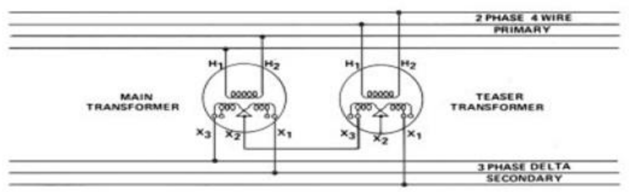

Fig .26. Represents Scott Connection Three-Phase to Three-Phase

In the case of a factory being built in a district that is at present served by a two-phase system, three-phase rather than two-phase motors would probably be installed in the factory, since these are more standard, and since there is a good chance of the two-phase system being changed over to three-phase at some future date. Here the utility is faced with the problem of supplying three-phase power from a two-phase system. The Scott connection with three-phase on the secondary performs this function. In this case, the currents in the secondary windings are 15 1/2% greater than in transformers delivering the same kva single-phase at the same voltage. This again causes the kva output of transformers with Scott taps in the secondary to be 86.6% of regular transformers of the same physical size. This connection is for additive polarity units and gives standard angular displacement.

5.1. Instantaneous Active and Reactive Power and Current Strategies

The power-electronic-based loads such as adjustable speed drives, rectifier equipment used in telecommunication networks, power supplies, domestic appliances, etc offer highly nonlinear characteristics. These nonlinear loads draw non-sinusoidal currents from ac mains and cause reactive power burden and excessive neutral current. They are also responsible for lower efficiency and interference of distribution system with the nearby communication networks. To improve the efficiency, capacitors are employed which also leads to the improvements of power factor of the mains. On the other hand, to reduce the interference with the communication network due to harmonics in the current flowing in the distribution system, passive-filters are used. But they have the limitations of fixed compensation, large size, and that they can create new system resonance. Present work mainly focused on two control strategies *p-q* and *id-iq* by using two controllers *i.e.*, fuzzy and PI. Instantaneous active and reactive theory (*p-q* theory) was introduced by H. Akagi, kawakawa, and Nabae in 1984. Since then, many scientists and engineers made significant contributions to its modifications in three- phase four-wire circuits and its applications to power electronic equipment. The *p-q* theory based on a set of instantaneous powers defined in the time domain. No restrictions are imposed on the voltage and current waveforms, and it can be applied to three phase systems with or without neutral wire for three phase generic voltage and current waveforms. Thus it is valid not only in the steady state but also in

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the transient state. *p-q* the-ory needs additional PLL circuit for synchronization so *p-q* method is frequency variant. In *id-iq* method angle "θ" is calculated directly from main voltages and thus enables the method to be frequency independent. Thus large numbers of synchronization problems with un-balanced and non-sinusoidal voltages are also avoided. The PI controller requires precise linear mathematical models, which are difficult to obtain and may not give satisfactory performance under parameter variations. Load disturbances, etc. Recently, fuzzy logic controllers have received a great deal of interests in APF. The ad-vantages of fuzzy controllers over conventional control-lers are that they do not need an accurate mathematical model, can work with imprecise inputs, can handle non-linearity, and are more robust than conventional controllers. The Mamdani type of fuzzy controller used for the control of APF gives better results compared with the PI controller, but it has the drawback of a larger number of fuzzy sets and rules. This increases the complexity of the controller; hence, this demands large computational time. As a result, it may not be useful for real-time applications with small sampling time. When the supply voltages are balanced and sinusoidal, both *p-q* and *id-iq* c

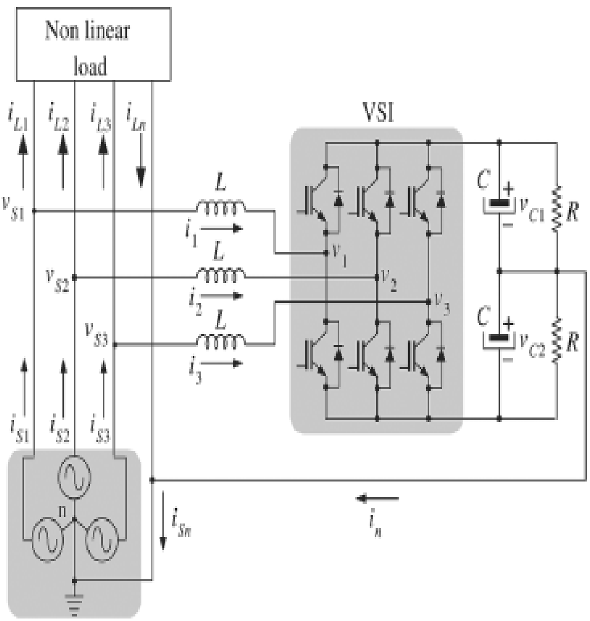

Fig .27. Three-leg shunt APF with non-linear load

Control strategies are converge to the same compensation characteristics but when the supply voltages are distorted and/or un-balanced sinusoidal, these control strategies result in different degrees of compensation in harmonics. The *p-q* control strategy is unable to yield an adequate solution when source volt-ages are not ideal. PI controller fails to respond quickly because of non-linear nature in the system, so we are developing soft computing techniques to analyze the performance of system under distorted condition. Fuzzy supports with outstanding performance under any volt-age conditions. On observing *id-iq* method with fuzzy logic controller gives awayan out-standing performed

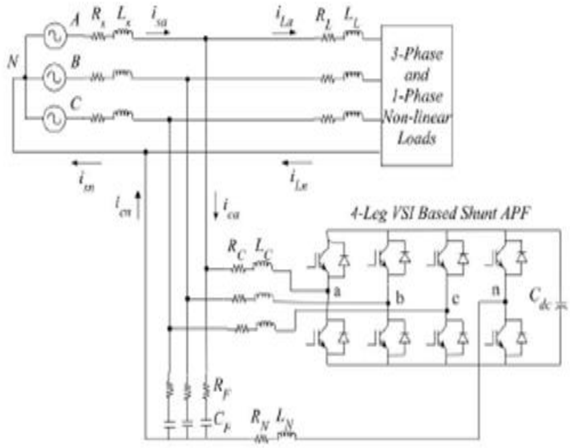

Fig .28. Four-leg shunt APF with non-linear load

The entire reference current generation scheme has been illustrated. The load currents *iLa*, *iLb* and *iLc* are tracked upon which Park's transformation is per-formed to obtain corresponding *d-q* axes currents *iLd* and *iLq* as given, where rotational speed of synchronously rotating *d-q* frame. According to *id-iq* control strategy, only the average value of d-axis component of load current should be drawn from supply.

Here *iLd1h* and *iLq1h* indicate the fundamental frequency component of *iLd* and *iLq*. The oscillating components *iLd* and *iLq*, *i.e.*, *iLdnh* and *iLqnh* are filtered out using low-pass filter.

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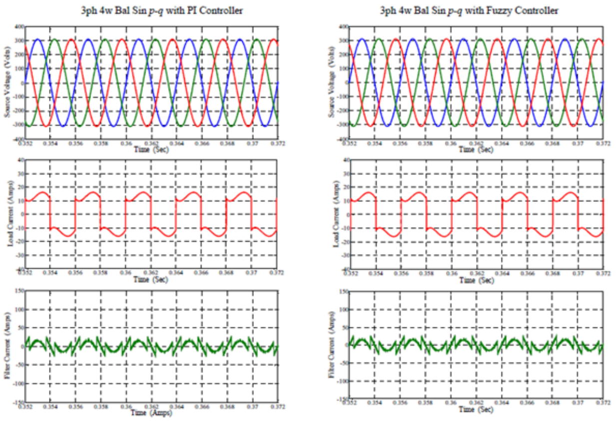

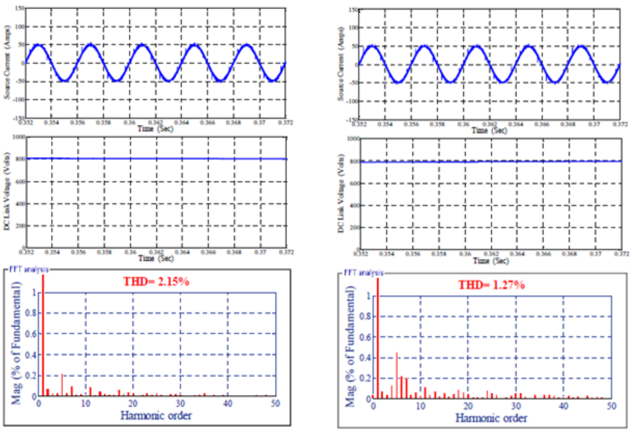

Figure shows the internal structure of the control circuit. The control scheme consists of PI controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a PI controller, which contributes to zero steady error in tracking the reference current signal. The output of the PI con-troller is considered as peak value of the supply current (*I*max), which is composed of two components: a) funda-mental active power component of load current, and b) loss component of APF; to maintain the average capacitor-tor voltage to a constant value. Peak value of the current (*I*max) so obtained, is multiplied by the unit sine vectors in phase with the respective source voltages to obtain the

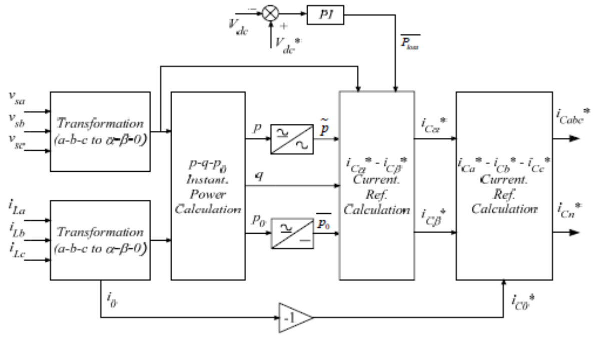

Fig .29.. Reference current extraction with conventional *p-q* method

In the present paper two control strategies; instantaneous real active and reactive power control strategy (*p-q*) and active and reactive current control strategy (*id-iq*) are developed and verified with three phase four wire system by using two different controllers PI controller as well as fuzzy controller. Though the two strategies are capable to compensate current harmonics in the 3 phase 4-wire sys-tem, but it is observed that instantaneous active and reactive current *id-iq* control strategy with fuzzy controller lead always better result under balanced, un-balanced and non-sinusoidal voltage conditions over remaining On contrast *p-q* theory needs additional PLL circuit for synchronization so *p-q* method is frequency variant, where as in *id-iq* method angle "*θ*" is calculated directly from main voltages and thus enables the method to be frequency independent. Thus large numbers of synchronization problems with un-balanced and non-sinusoidal voltages are also avoided. Addition to that DC voltage regulation system valid to be a stable and steady-state error free system was obtained.

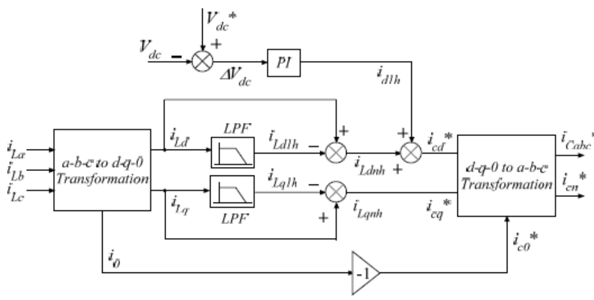

Fig .30. Reference current extraction with *id-iq* method

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To employ APFs in three-phase four-wire systems, two types of configurations are possible; one is a three-leg structure with the neutral conductor being connected to midpoint of dc-link capacitor ; and the other one is a four-leg structure, where a fourth leg is provided exclusively for neutral current compensation.

Despite the fact, this topology is seldom preferred owing to less number of switching devices and lower switching losses compared to the eight-switch topology. How-ever, the higher order harmonics generated in the eight switch configuration due to frequent switching of semi-conductor devices can be eliminated by the use of RC high-pass filter as shown in **and** switching losses occurring in the VSI can also be minimized by the use of DC-link voltage regulator.

Moreover, the four- leg APF has simple dc-link voltage controller, requires small dc-link capacitor, and the control sachem

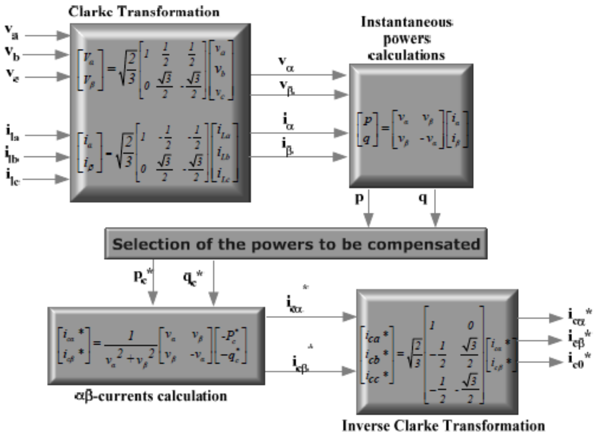


Fig. 31. Control method for Shunt current compensation based on *p-q* theory

MATLAB

6.1. Introduction to Mat lab

Mat lab is a high-performance language for technical computing. The name mat lab stands for matrix laboratory. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building.

Matlab is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN.

6.2. History of Matlab

Cleve Barry Moler, the chairman of the computer-science department at the University of New Mexico, he is a mathematician and computer programmer specializing in numerical analysis. Started developing MATLAB in the late 1970s. He designed it to give his student's access to LINPACK and EISPACK without their having to learn FORTRAN. It soon spread to other universities and found a strong audience within the applied mathematics community. Jack Little, an engineer, was exposed to it during a visit Moler made to Stanford University in 1983. Recognizing its commercial potential, he joined with Moler and Steve Bangert. They rewrote MATLAB in C and founded Math Works in 1984 to continue its development. These rewritten libraries were known as JACKPAC. In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK.

6.3. Strengths of Matlab

- MATLAB is relatively easy to learn.
- MATLAB code is optimized to be relatively quick when performing matrix operations.
- MATLAB may behave like a calculator or as a programming language.
- MATLAB is interpreted, errors are easier to fix.

- Although primarily procedural, MATLAB does have some object-oriented elements.

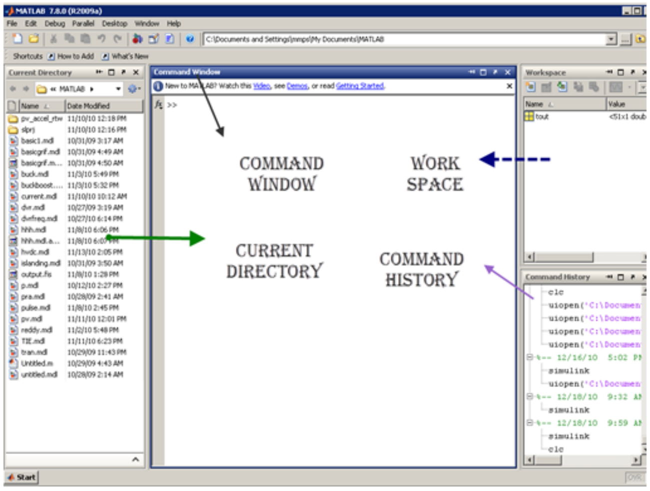
Other features:

- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, FORTRAN, Java, COM, and Microsoft Excel.

6.4. Components of Matlab

- Workspace
- Current Directory
- Command History
- Command Window

Block diagram of Mat lab components



6.5. MATLAB and engineering

MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing. However, many researchers mostly from Computer Science background feel that MATLAB should be used only for mathematical analysis necessary in image processing and not for implementation of image processing software. Moreover, MATLAB should not be used to simulate computer architectures, systems software and computer networks unless while solving some numeric problem.

6.6. Toolboxes in Matlab

- Simulink
- Fuzzy
- Genetic algorithm
- Neural network
- Wavelet

6.7 Simulink

➢ Introduction

Simulink is a software add-on to mat lab which is a mathematical tool developed by The Math works,(http://www.mathworks.com) a company based in Natick. Mat lab is powered by extensive numerical analysis capability. Simulink is a tool used to visually program a dynamic system (those governed by Differential equations) and look at results. Any logic circuit, or control system for a dynamic system can be built by using standard building blocks available in Simulink Libraries. Various toolboxes for different techniques, such as Fuzzy Logic, Neural Networks, DSP, Statistics etc. are available with Simulink, which enhance the processing power of the tool. The main advantage is the availability of templates / building blocks, which avoid the necessity of typing code for small mathematical processes.

➢ Concept of signal and logic flow

In Simulink, data/information from various blocks are sent to another block by lines connecting the relevant blocks. Signals can be generated and fed into blocks dynamic / static).Data can be fed into functions. Data

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can then be dumped into sinks, which could be scopes, displays or could be saved to a file. Data can be connected from one block to another, can be branched, multiplexed etc. In simulation, data is processed and transferred only at discrete times, since all computers are discrete systems. Thus, a simulation time step (otherwise called an integration time step) is essential, and the selection of that step is determined by the fastest dynamics in the simulated system.

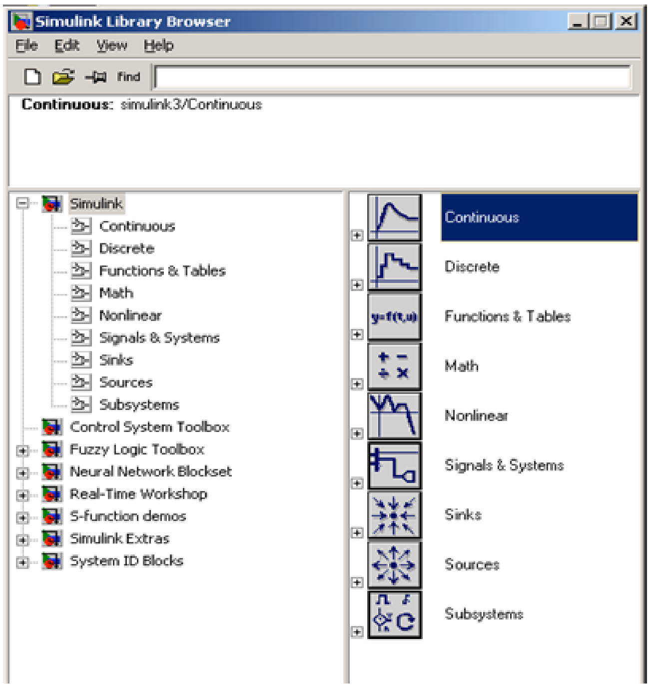
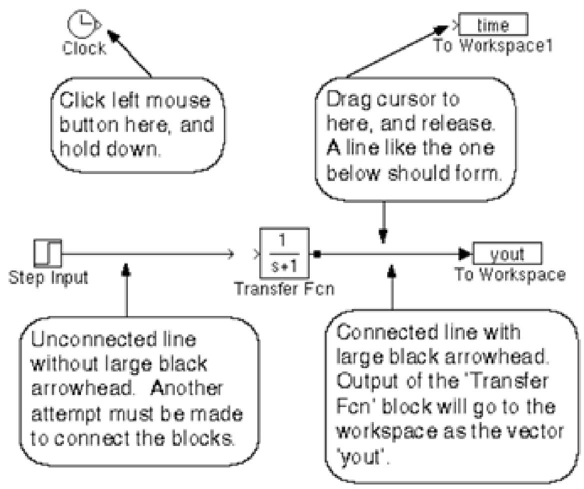


Fig Simulink library browser

➢ Connecting blocks



To connect blocks, left-click and drag the mouse from the output of one block to the input of another block.

Sources and sinks:

The sources library contains the sources of data/signals that one would use in a dynamic system simulation. One may want to use a constant input, a sinusoidal wave, a step, a repeating sequence such as a pulse train, a ramp etc. One may want to test disturbance effects, and can use the random signal generator to simulate noise. The clock may be used to create a time index for otting purposes. The ground could be used to connect to any unused port, to avoid warning messages indicating unconnected ports.

The sinks are blocks where signals are terminated or ultimately used. In most cases, we would want to store the resulting data in a file, or a matrix of variables. The data could be displayed or even stored to a file. The stop block could be used to stop the simulation if the input to that block (the signal being sunk) is non-zero. Figure 3 shows the available blocks in the sources and sinks libraries. Unused signals must be terminated, to prevent warnings about unconnected signals.

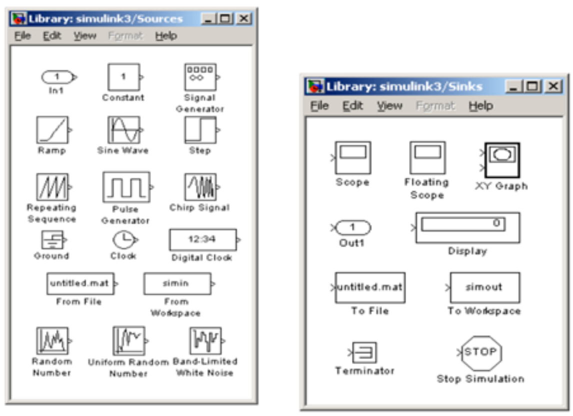


Fig Sources and sinks

➢ Continuous and discrete systems

All dynamic systems can be analyzed as continuous or discrete time systems. Simulink allows you to represent these systems using transfer functions, integration blocks, delay blocks etc.

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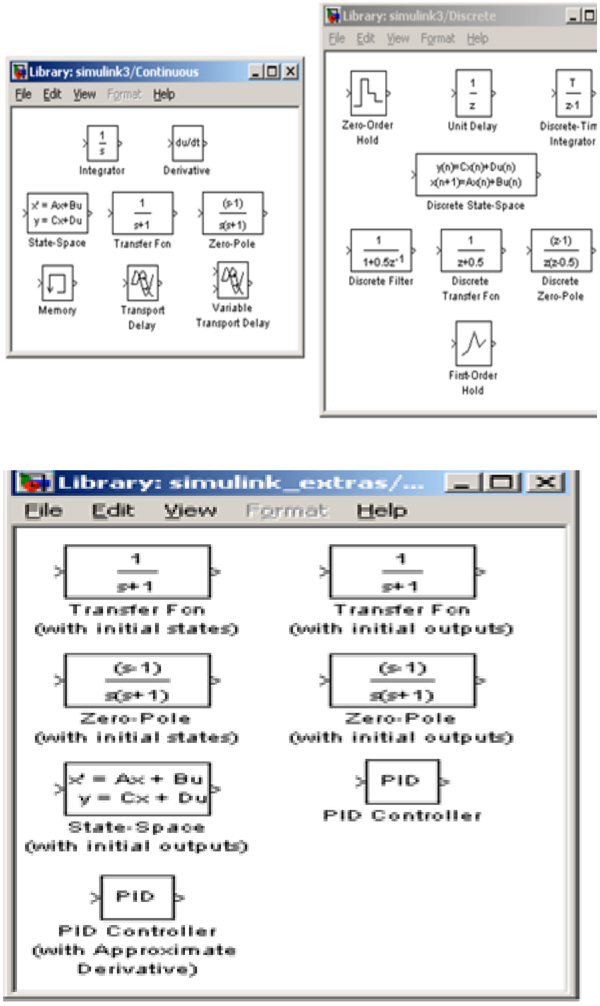

fig continous and descrete systems

➢ Non-linear operators

A main advantage of using tools such as Simulink is the ability to simulate non-linear systems and arrive at results without having to solve analytically. It is very difficult to arrive at an analytical solution for a system having non-linearities such as saturation, signup function, limited slew rates etc. In Simulation, since systems are analyzed using iterations, non-linearity's are not a hindrance. One such could be a saturation block, to indicate a physical limitation on a parameter, such as a voltage signal to a motor etc. Manual switches are useful when trying simulations with different cases. Switches are the logical equivalent of if-then statements in programming.

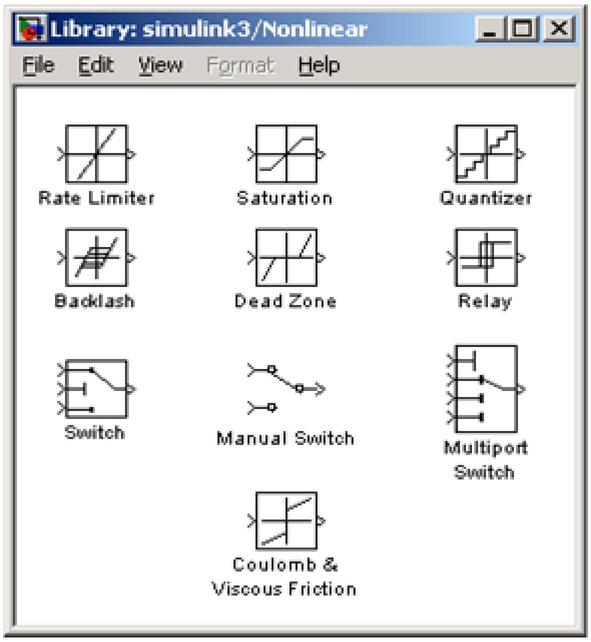

fig simulink blocks

➢ Mathematical operations

Mathematical operators such as products, sum, logical operations such as and, or, etc. can be programmed along with the signal flow. Matrix multiplication becomes easy with the matrix gain block. Trigonometric functions such as sin or tan inverse (at an) are also available. Relational operators such as 'equal to', 'greater than' etc. can also be used in logic circuits.

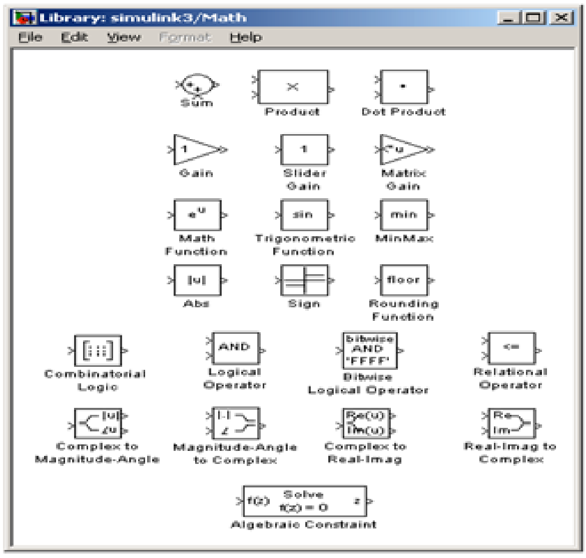

Fig Simulink math blocks

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➢ Signals & data transfer

In complicated block diagrams, there may arise the need to transfer data from one portion to another portion of the block. They may be in different subsystems. That signal could be dumped into a GOTO block, which is used to send signals from one subsystem to another.
Multiplexing helps us remove clutter due to excessive connectors, and makes matrix (column/row) visualization easier.

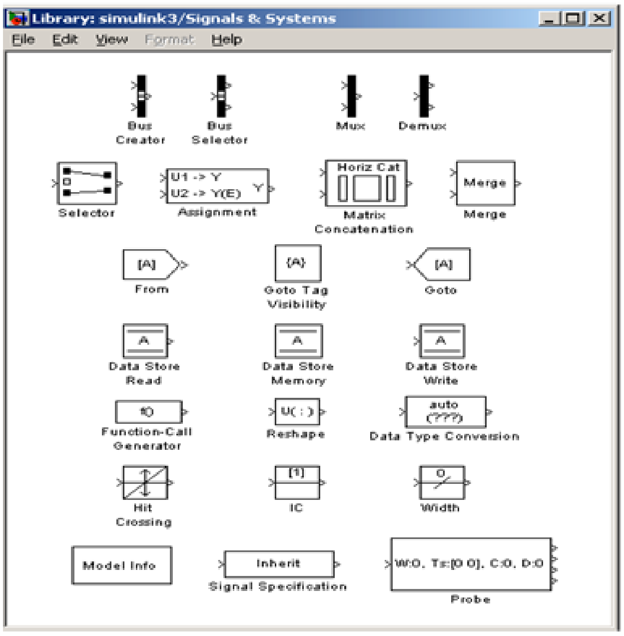


Fig signals and systems

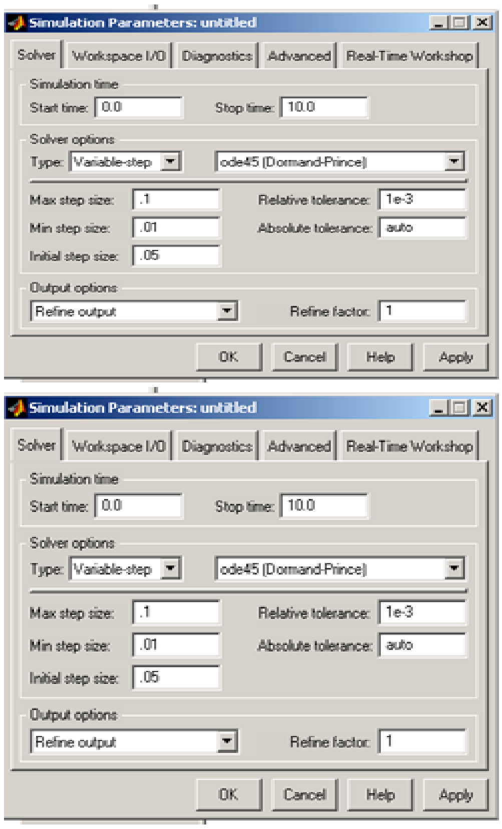
➢ Making subsystems

Drag a subsystem from the Simulink Library Browser and place it in the parent block where you would like to hide the code. The type of subsystem depends on the purpose of the block. In general one will use the standard subsystem but other subsystems can be chosen. For instance, the subsystem can be a triggered block, which is enabled only when a trigger signal is received.

Open (double click) the subsystem and create input / output PORTS, which transfer signals into and out of the subsystem. The input and output ports are created by dragging them from the Sources and Sinks directories respectively. When ports are created in the subsystem, they automatically create ports on the external (parent) block. This allows for connecting the appropriate signals from the parent block to the subsystem.

➢ Setting simulation parameters

Running a simulation in the computer always requires a numerical technique to solve a differential equation. The system can be simulated as a continuous system or a discrete system based on the blocks inside. The simulation start and stop time can be specified. In case of variable step size, the smallest and largest step size can be specified. A Fixed step size is recommended and it allows for indexing time to a precise number of points, thus controlling the size of the data vector. Simulation step size must be decided based on the dynamics of the system. A thermal process may warrant a step size of a few seconds, but a DC motor in the system may be quite fast and may require a step size of a few milliseconds.



Simpower system

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Introduction

SimPowerSystems software and other products of the Physical Modeling product family work together with Simulink software to model electrical, mechanical, and control systems.

SimPowerSystems software operates in the Simulink environment. Therefore, before starting this user's guide, make yourself familiar with Simulink documentation. Or, if you perform signal processing and communications tasks (as opposed to control system design tasks), see the Signal Processing Block set documentation.

The Role of Simulation in Design:

Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems. Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation.

Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance objectives.

SimPowerSystems software is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. It uses the Simulink environment, allowing you to build a model using simple click and drag procedures. Not only can you draw the circuit topology rapidly, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library.

Since Simulink uses the MATLAB computational engine, designers can also use MATLAB toolboxes and Simulink block sets. SimPowerSystems software belongs to the Physical Modeling product family and uses similar block and connection line interface.

Sim power systems Libraries

SimPowerSystems libraries contain models of typical power equipment such as transformers, lines, machines, and power electronics. These models are proven ones coming from textbooks, and their validity is based on the experience of the Power Systems Testing and Simulation Laboratory of Hydro-Québec, a large North American utility located in Canada, and also on the experience of École de Technology Superior and University Laval. The capabilities of SimPowerSystems software for modeling a typical electrical system are illustrated in demonstration files. And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies.

The SimPowerSystems main library, powerlib, organizes its blocks into libraries according to their behavior. The powerlib library window displays the block library icons and names. Double-click a library icon to open the library and access the blocks. The main powerlib library window also contains the Powergui block that opens a graphical user interface for the steady-state analysis of electrical circuits.

Nonlinear Simulink Blocks for Simpower systems Models

The nonlinear Simulink blocks of the powerlib library are stored in a special block library named powerlib models. These masked Simulink models are used by SimPowerSystems software to build the equivalent Simulink model of your circuit. See Improving Simulation Performance for a description of the powerlib models library.

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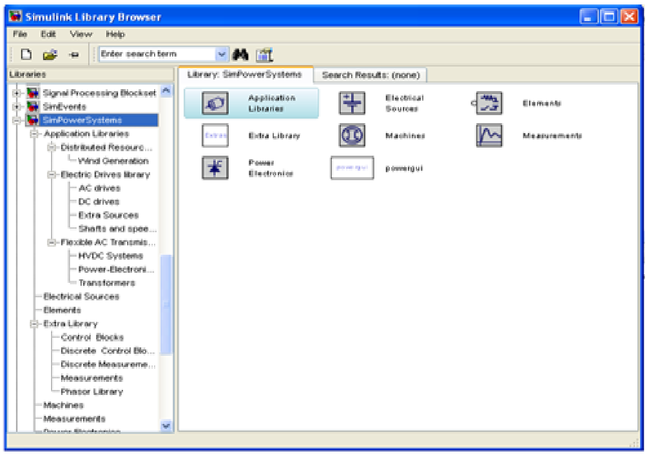
Diagram of simpower system



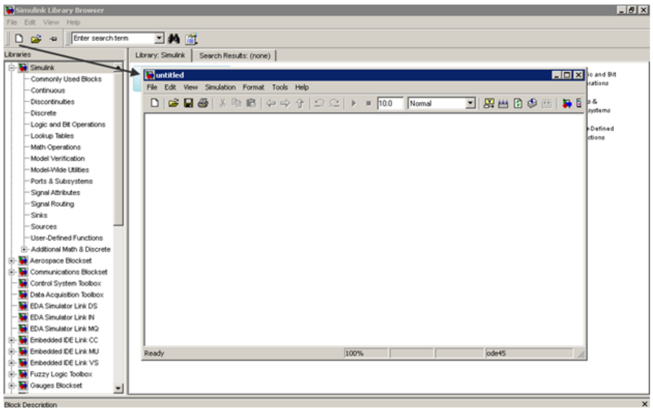
Applications of Matlab:

MATLAB is a data-manipulation software package that allows data to be analyzed and visualized using existing functions and user-designed programs. MATLAB is a numerical computing environment and programming language. MATLAB allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. Although it specializes in numerical computing, an optional toolbox interfaces with the Maple symbolic engine, allowing it to be part of a full computer algebra system.

Some of the mat lab applications listed are

- Orthogonal frequency division multiplexing
- Genetic algorithm data mining
- Speech recognition using VQ method
- Channel Estimation and Detection in DS-CDMA
- Analysis of iterative channel estimation and multi-user detection in multi path DS-CDMA channels
- Time-domain signal detection
- Time-domain signal detection based on second-order statistics for mimo-OFDM systems
- Space–time block coding
- Space–time block codes for mimo channels
- Blind channel estimation

Click on the file and select new model file and a file will be appeared:



Now a block and right click on it, the block will be appearing in the new model file (untitled)

For example consider a sine wave in the source block and in order to obtain or to view the output place the scope block. Join those two blocks. Now a simple circuit is ready, now set the simulation time in the tool bar (default it is set to 10.0), simulate the circuit by clicking on the simulation icon (PLAY BUTTON). Simulation is completed now by double clicking on the scope u can view the output, press the auto scale button and o/p will appear clearly.

7.1. Simulation Results

The scheme shown in Fig. 1 is modeled using the space vector representation of the state variables, at a 10 kHz sampling rate. Both, the V-V and Scott transformers are included in these simulations. The railroad system is represented using the measured harmonic currents distribution, injected to the power system in the secondary side of each transformer. The three-phase power system is modeled using a space vector Thevenin equivalent. Also, space vector representations of the Power transformer (V-V or Scott), three-phase (VSC), and the filter are used in the simulation. For the railroad case, the measured harmonic current spectrum is injected in one secondary phase .The simulation uses maximum unbalance by operating on one.

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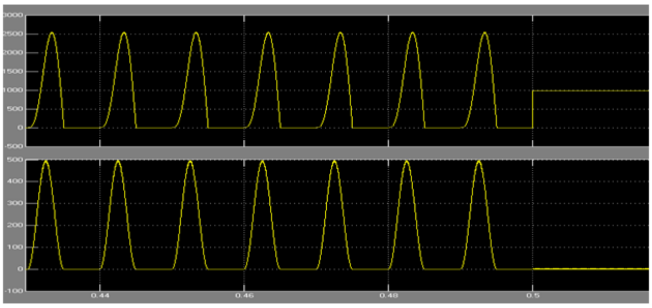


Fig .32 represents Active and reactive power variations for non linear loads

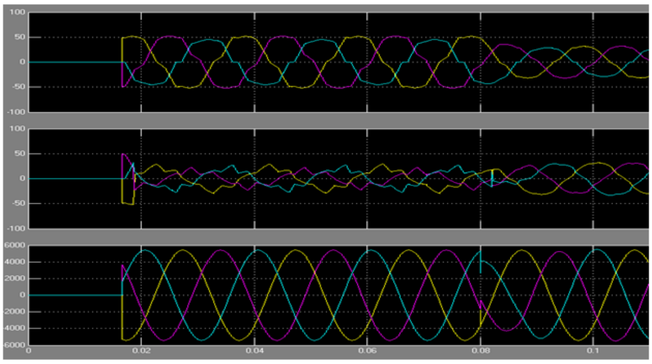
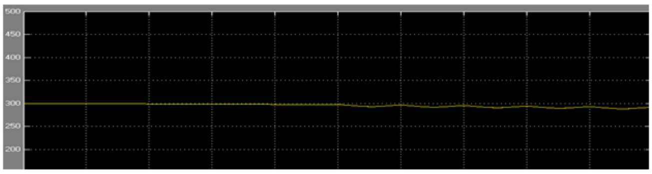
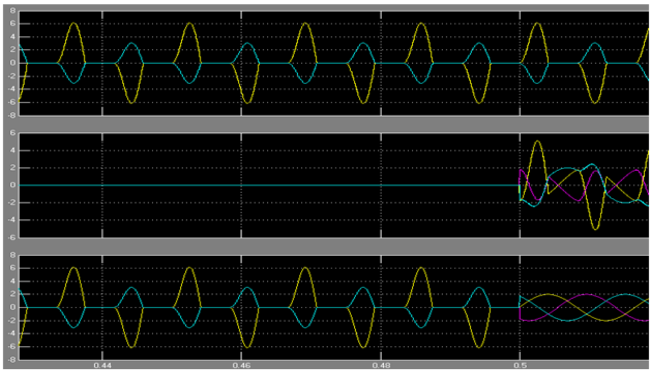


Fig .33 represents simulated waveforms for the Scott transformer connection for different Railroad load profiles

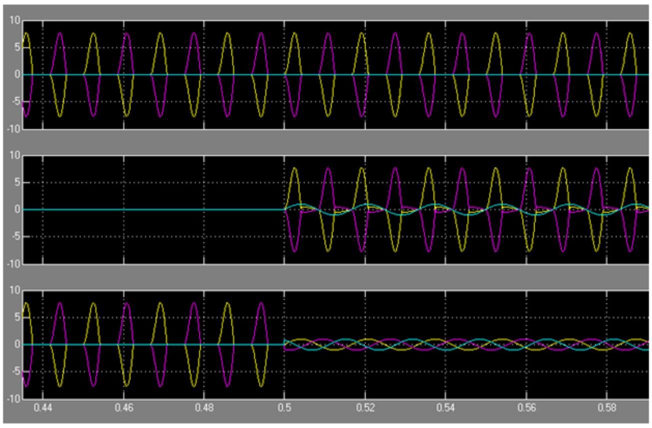
Fig a,b,c represents Un compensation wave current, filter and compensate currents



\Fig.34 represents V dc



Figs .35 represent Scott connection uncompensated, filter& compensated currents



Figs .36 represent v- v connection uncompensated, filter& compensated currents

CONCLUSION

The proposed concept is extended for non linear loads or unbalanced loads by using MATLAB/SIMULATION software and results are verified and the simulated waveforms are verified for both linear and non linear loads and compared.

Also, the compensation method based on the instantaneous power control algorithm with direct space vector representation, reduces the System's current THD to allowable ranges (<20%) and reduces the overall unbalance from 97% to 18% for worse-case operation. The compensation algorithm is able to control the power factor measured at the common coupling point under all considered conditions, with a very short transient thanks to the fast dynamic response of DPC.

The distortion that remains in the compensated current is mainly due to the distortion in the grid voltage and the limitations of the switched nature of the filter's power stage, that is, unable to compensate very fast transients present.

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