74. LV Three Phase Automatic Load Balancing System

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Abstract

The future power grid is going to be smart. It will be incorporating many sources and power generation including conventional, renewable and alternate. These resources will cause bidirectional power flow though out the grid. Preposition of connected load and sources will become ever more complex and difficult to understand and handle. Due to unknown connected loads and sources, load balancing on the lower voltage side will be become a much complex problem. This paper deals with improved method of balancing on low voltage side of three phase four wire power system. Power distribution companies normally face problem of imbalance of currents and voltages as loads; especially in residential areas loads vary continuously and unwarranted. Many a times, random fluctuation result in one phase being overloaded, while others are relieved. Imbalance in power system causes problems of voltage drops, excessive energy losses, risk of transformer overload and sometimes results in blackouts. In order to achieve optimal performance of secondary distribution, imbalance problem need to be resolved. This can be achieved by using phase swapping technique. An efficient algorithm is presented in this paper for improved performance of power distribution system. Load balancing method has been proposed using state of the art computation hardware. It will compare output currents on each phase and estimate loads of all each phase with the help of current transformer. Phase swapping algorithm is executed using a digital controller that will take the loads of all phases as input and it will present a scheme of phase distribution to the single phase loads as an output. The phases are then swapped as per the output scheme by using solid state relays and contactors. Equal distribution of load among phases in a three-phase power system is the outcome which reduced current flowing through the neutral wire to minimum

Keywords: *Smart Grid;Phase Swapping; Phase Balancing; Low voltage distribution Systems;Optimization algorithm;Triac Based Switching,Break Before Make Strategy*

1. Introduction

Electric Power is distributed to the commercial and residential areas mostly in 3 phase - 4 wire system. Electric Power is generated in 3-phases at the generating plant with winding placed at 120 degree apart, whereas most loads at the consumer end is single phase load. Resultantly, distribution network is configured in a way that the houses are connected with different phases, with some house supplied with phase A, and others with phase B or phase C.
The loads at the user end is very much unpredictable and of varying nature. Commercial users are using more power during the working hours; the residential load is mostly high during the night hours.This varying nature of loads is prone to causing unbalance and makes it difficult to balance the loads properly when loads are distributed over different phases.[1]

The loads of all three phases should be balanced as precisely as possible for the efficient utilization of the electric power. If one phase is overloaded, while the other two are relieved, this will create unbalance in the power network. This results in the excessive flow of current through the neutral wire [2-3]. It also adds to the problem of voltage overheating of the power equipment, and many other problems which hinders the efficient transfer of the electric power.

It is a matter of great concern and challenge for the distribution engineer to balance the load on all the

three phases at all time. Normally the load is manually shifted from one phase to another in an attempt to create balance. This process mostly rely on personal experience and it also causes frequent service interruptions. With the advent of smart technology and the methods of injection of power to the local grid by the user, the power distribution network would become more complex and the manual balancing of phases method would render impossible. There is the need to introduce method of automatic balancing of loads among different phases for catering future needs.
There are many techniques proposed to improve the current and voltage unbalance problem in the distribution network. The use of special transformers, like "Scott" transformer, improves the imbalance problem, but such solutions are very expensive[1]. There are many papers which focuses on solving the issue [4],[5],[6],[7], but the computational time of these methods was very high and it is sometimes impossible to apply practically. No paper deals with the issue of inrush current during the 'switching phase'.

In this paper, we present a scheme which could easily handle the imbalance network issue at a very low cost. The proposed algorithm has low computation time and the proposed hardware can cheaply be added to the existing distribution system, enabling the automatic swapping of phases when necessary. Special circuit is designed which uses switching mechanism, ensuring very less inrush current during the switching period.

2. Problem Description

The load unbalance in an electric grid system should be rectified as soon as possible, owing to the fact that it causes great harm to the electric grid. Normally, these harmful effects are ignored which results in poor utilization of electric power. Some of the problems are highlighted as follows:

2.1 Neutral Current

In three phase system, the current flowing through the neutral wire is the vector sum of the current in all three phases

$$I_{neutral} = I_a + I_b + I_c \tag{1}$$

It adds up to the magnitude of zero in a balanced system .But if any of the phase is overloaded , load imbalance occurs due to which significant amount of current starts flowing through neutral wire .The excessive neutral current leads to considerable amount of voltage drop across the wire which results in overheating of the wire metal.

2.2 Voltage Imbalance

For balanced conditions, the three phase voltages are 120 degrees apart from each other and only positive phase sequence exist. There is no negative and zero phase sequence in case of balanced load. Balanced three phase voltage is

$$V_a = |V_a| \angle 0^0, \qquad V_b = |V_b| \angle 120^0, \qquad V_c = |V_c| \angle 240^0 \tag{2}$$

But unbalancing in load induces an opposing magnetic field which opposes the rotation of generator, resulting in voltage imbalance [8-9].

In the figure below, see Fig.1 it is shown that in LV side due to unbalance of load, the voltages in three phases shows deviation and phase vectors changes which results in negative and zero phase sequences.

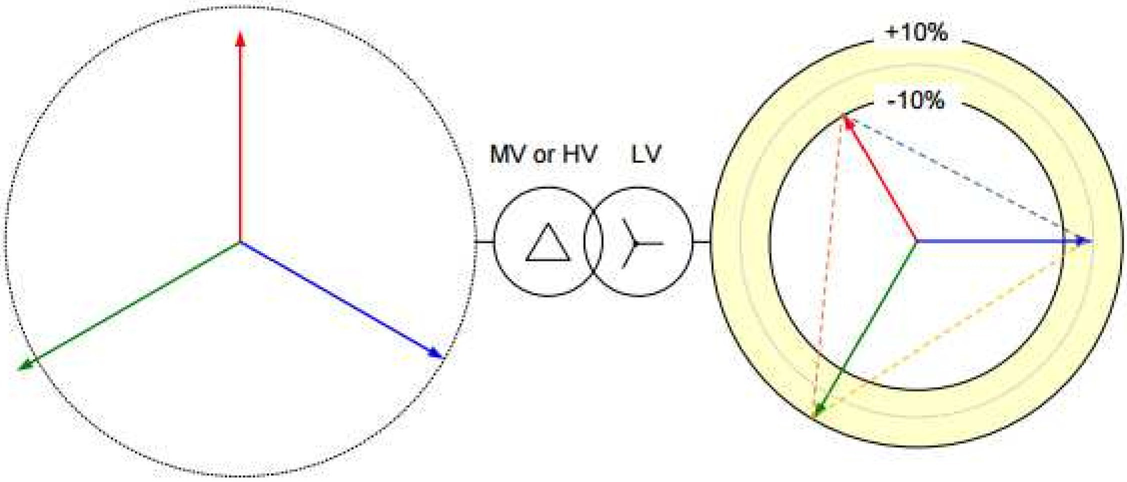


Fig1: Voltage imbalance due to unbalance loads

The adverse effects of voltage imbalance on our power system are:

2.2.1 Extra Power Loss

Voltage imbalance is responsible for higher power loss. The more the voltage unbalance ratio (VUR),the more will be the power loss which should be catered.Voltage imbalance is given by

$$V_a = |V_a| \angle a, \qquad V_b = |V_b| \angle b, \qquad V_c = |V_c| \angle c \qquad (3)$$

Where $|V_a| \neq |V_b| \neq |V_c|$ and $\angle a \neq \angle b + 120) \neq \angle(c - 120)$

2.2.2 Motor Failure

Normally motor operates on positive phase sequence and produces a positive torque.Due to high voltage, unbalance ratio(VUR) phase sequence changes from positive to negative or zero depending upon the amount of imbalance and leads to raise in the winding temperature of motor to a large extent.Moreover due to negative phase sequence, motor encounters an opposite torque which leads to motor noise,vibration and malfunction.

2.2.3 Transformer Efficiency:

Three phase voltage unbalance ratio(VUR) also effects the transformer health.It causes the flux inside the transformer to be asymmetrical, leading to extra core losses,increase in winding temperature and may leads to decrease in transformer efficiency to a large extent[10].

2.3 Copper loss

The copper loss is given as $P = i^2R$. Due to the unbalance, a large amount of power is lost in transmission lines and in the loads [11, 12].
In balanced case, Power loss in three phase is given as

$$P = 3\, i^2 R \qquad (4)$$

In unbalance case, power loss is given as considering I_r,I_y,I_b to be flowing in three phases as:

$$P = {i_r}^2 R + {i_y}^2 R + {i_b}^2 R \qquad (5)$$

Eq. (4) states the power loss under balanced condition and eq. (5) states the power loss under unbalance condition.Now extra power loss due to unbalance can be compared by subtracting eq. (5) from eq. (4):

$$\text{Power loss unbalanced load} = \text{eq.}(5) - \text{eq.}(4)$$

So a large amount of power is loss in lines and phases due to load unbalancing.

2.4 Neutral Phase Shift

The unbalance in current results in neutral phase shift because if the distribution lines are not balanced, the line to neutral voltage at load end will have different phases and magnitudes. Due to this, current flowing through the phases will have different values and cause different voltage drops resulting in shifting of the neutral. This neutral shift causes the phase voltages to rise at a very high level resulting in dielectric breakdown of insulation and arcing.

More over line impedances and reactive power also increase to a significant extent, and it affects the distribution system badly and need to be catered.

3 Proposed Approach

In order to rectify the above mentioned power distribution issues and to ensure efficient deliverance of electric power to the end users, a hardware technique is proposed which will cater the unbalancing issue during the normal operation of the power system. Currents at different nodes are measured by the measuring device and all nodal currents are transferred from the slave unit to the master unit placed centrally. The master unit is designated to do all the major computations and to decide which phases are to be swapped at different load points as to reduce the unbalance from the system. The resulting phases shift scheme is then communicated from the master unit to respective slave units to do the phase swapping.

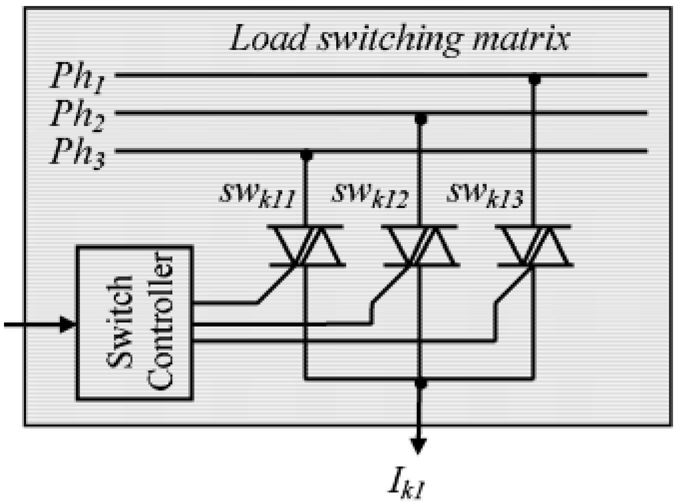


Fig2: Triac Based Switching

The hardware configuration at the nodes end is as shown (See Fig2). The triac based switching circuit is connected to each of the three phases. It is ensured that only one relay is turned on at one time, otherwise, it will result in the shortening of the line-line voltage.

The master unit keeps check on the current flowing through the neutral wire. In case of current value greater than the level set by the utility company, the system takes all load values at each node and an efficient algorithm is executed which is explained below. The algorithm takes all node currents as an input and as an output controls the opening and closure of solid state relays at each load end.

3.1 Algorithm

The algorithm makes use of the difference in magnitudes of current in all three phases to solve the problem of unbalance distribution of loads among phases. The steps are as follows:

Step1:
Measuring current flowing through neutral wire by using current transformer.

Step2:
If current through the neutral wire is greater than the value set by the utility company, the system activates. If not, no further action takes place.

Step 3:
The slave controllers, placed at each of the nodes, measures the current of each node and communicate the value to the master unit to be used as an input.

Step 4:
Average ideal current is calculated by taking sum of all the node currents and dividing the result by 3.

$$I_{avg} = \frac{I_a + I_b + I_c}{3}$$

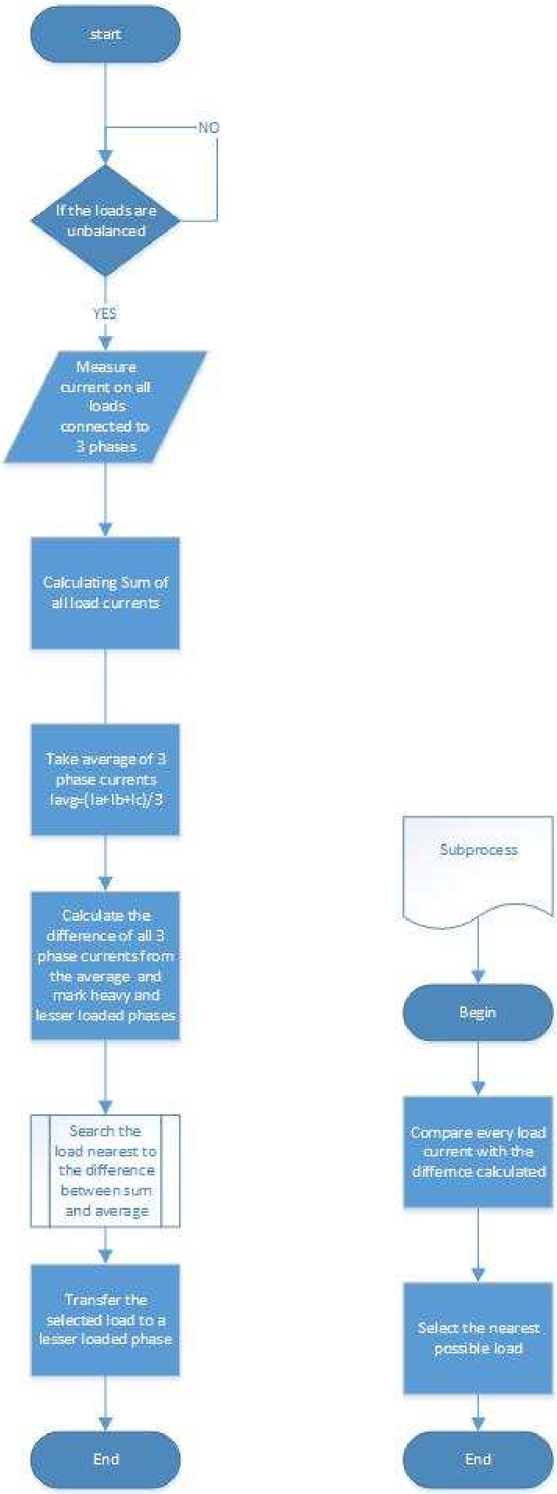
This average current is the magnitude of current which if flows through each phase would nearly balance the system and results in the reduction of current flowing through the neutral wire.

Step 5:
Mark the heavily and lightly loaded phases by calculating the difference between the actual phase current and the I_{avg}. Store this difference in current values in an array. By this, it is known how much magnitude of current is to be shifted from the heavily loaded phase to the lightly loaded phase.

Step 6:
Iterate over by comparing each node current with the 'difference current value' calculated previously and select the node having the nearest possible current value to the 'difference current value'.

Step 7:
After marking the particular load which is to be shifted, give control signal to the relay placed at node end. It will shift that particular load from heavily loaded phase to the lightly loaded phase.

Step 8:
Repeat the whole process until the neutral current reached that which is under the permissible range set by the utility company.



4 Switching mechanism:

It is very crucial to ensure that the three triacs of solid state relays should operate in a way that no two triacs are in the 'on state' at the same time, otherwise, this will create short circuit among phases. There exists many ways by which solid state relays could be operated during switching [13].

- Zero Crossing Strategy
- Random Switching
- Pie Switching Strategy

Zero crossing strategy is switching on the triac at zero voltage and switching it off at zero current. This is best method for resistive loads only since voltage and currents are in phase. But in case of inductive loads, this switching mechanism is not preferable as it leads to high inrush current as evident from the equation which is found by using Laplace transform and convolution integral.

$$i(t) = \frac{\hat{v}}{\sqrt{R^2 + \omega^2 L^2 \left[\sin(\omega t + \varphi_0 - \varphi) - \sin(\varphi_0 - \varphi).e^{\frac{t}{\tau}}\right]}} \tag{6}$$

Here,$= \frac{L}{R}$,$\varphi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

Random Switching is switching on the triac instantly on receiving the control signal at any phase angle of voltage without waiting for zero crossing and switching it off at zero crossing of current. This is far better than zero crossing strategy as its leads to considerable amount of low inrush current compared to zero crossing mechanism. Given below is the **schematic of three phase switching** successfully implemented on the **"proteussoftware".(**See Fig3)

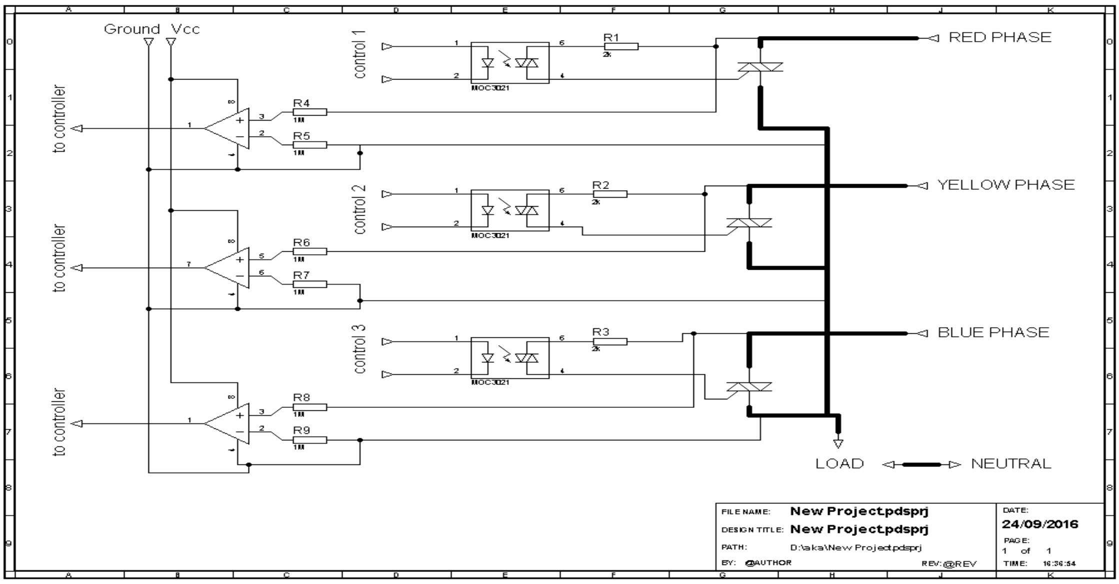


Fig3: 3Phase switching mechanism using Triacs ,Optocupler and Opamps

An important thing to consider is that no two triacs are in an 'on state' at the same time as this leads to line to line short circuit. To ensure this, a '**break before make'** strategy is proposed as shown in the figure ABOVE. Op-amp, used as a comparator, is connected across the triac and its reference voltage is set as 3V. When triac is in 'off state',a significant amount of voltage is dropped across the triac. On comparing this voltage drop with the reference voltage, op-amp outputs high signal which is detected by the gate circuitry. This ensures that the load is cut off from the phase voltage and it is now safe turn it on by supplying it through a different phase. This assures that only one triac is on at a time.

Pie Switching strategy is the best switching technique and this strategy determines the phase angle at a time when one triac is off and switches the other triac on that particular phase. This the best approach as from eq. (6), the DC part of the inrush current is avoided and it immediately leads to a stationary current. So this strategy eliminates the problem of inrush current which is very useful for sensitive devices.

5 Conclusion:

In this paper, an efficient algorithm is developed which could be implemented to solve the load unbalancing problem in the distribution network. The computation time of the algorithm is less and it could work well in a dense electrical network. A hardware is presented which can solve the problem of high inrush flow of current during phase switching. The switching strategy is closely focused as it is the main constraint while implementing such systems on a large scale.

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