Energy Conservation Through Load Balancing

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Abstract: The rapid growth of power system and the increasing trend of localized power generation will make the power system much more complex in the near future. The introduction of smart grid will result in bidirectional power flow throughout the power system. With the diverse spread of loads and sources on the low voltage side, load balancing would be a complex problem. This paper presents a novel method of load balancing on LT side of 3 phase 4 wire distribution transformer. Power engineers usually face problems with the balancing of loads on all three phases as the loads that are connected to the user end are of unpredictable and uncontrollable nature. Many a times, this causes overloading of one of the phase leaving others tobe relieved. Imbalance at the distribution end results in excess amount of the neutral current, voltage drops, transformers overloading, intense energy losses, and disrupts the efficient transfer of electrical energy. It is imperative that these issues should be catered. This can be done by implementing a phase swapping technique. The paper presents an algorithm for preparing an optimized scheme for balancing of loads among phases and also proposes load balancing method using state of the art computation hardware (triac based switching circuitry). The proposed system measures the unbalance in the current of all phases and estimate loads connected to the individual phases. Phase swapping algorithm is then executed which gives the best scheme for single phase loads to produce a balance system. Triac based switching is then used to swap phases and this results in balanced system with reduced amount of current flowing through the neutral. Lastly, the paper presents a switching strategy which if implied, reduces the inrush current to a considerable level.

Keywords: —energy conservation, load balancing, smart grid, triac based switching, phase identification.

I. INTRODUCTION

The distribution end of the power system is globally being configured with 3 phase 4 wire system. Within this system, the three phase wires and the neutral wire from the transformer secondary winding is distributed among the single phase loads in a manner that some loads are being supplied with one phase, whereas others with different phases. The loads connected are always being of unpredictable and uncontrollable nature. It is seen that they usually follow irregular pattern. Residential loads are normally at their peak during night hours, whereas the commercial loads are 'on' during working hours. This varying nature of loads creates unbalance in the system and it becomes challenging for the distribution engineers to distribute loads equally on all three phases [1]. It is necessary to balance loads equally on all three phases. If the load are not balanced properly, and any one phase is overloaded as compared the other phases, then this will result in excessive current flowing through the neutral wire [2], [3]. It also causes problems of voltage imbalance, de rating of wires, overloading of transformers, and disrupts the normal working of electrical equipment. In order to solve the unbalance issue, the distribution engineers manually shifts the load from over loaded phase to less loaded phase. This process needs personal training and it causes service interruption. The future complexities which would be introduced into the power system after the advent of smart grid technology which allows power injections to the grid from various customer points will make the manual method of load balancing impractical. It is a need of time to introduce an automatic method of load balancing among phases to solve the unbalance issue for catering future needs. Various techniques have been proposed to solve the imbalance in voltage and current in distribution system. Special transformers like Scott[1] improves the imbalance problem but these solutions are very costly. Many papers have focus on resolving the issue [4],[5],[6],[7] but their computational time is large and it is not feasible to implement them practically on large scale. More over issue of inrush current during switching is also neglected in all the above papers. In this paper, we propose an algorithm which has a less computation time and a hardware is presented which can be swiftly and cheaply be applied to an existing distribution system to solve the unbalance issue. A switching strategy is discussed in detail which reduces the heavy inrush current during switching to the very low level.

II. PROBLEM DISCRIPTION

The unbalance in the power system hinders the efficient deliverance of power to the consumers. If the current unbalance is not addressed instantly, it will contribute to other problems:

A. Neutral Current:

In a perfectly balanced system, the neutral current is zero since it is calculated as the vector sum of individual phase currents.

$$I_{neutral} = I_a \angle 0^0 + I_b \angle 120^0 + I_c \angle -120^0 \quad (1)$$

However when the current is not balanced, a tremendous amount of current flows through the neutral wire which adds to the heat loss in the neutral wire and sometimes result in burning of neutral wire , causing service interruption.

B. Voltage Imbalance:

The current imbalance also leads to voltage imbalance owing to extra copper losses in the distribution wires. Neutral to ground voltage increases and as a result phase to neutral voltage decreases. This decrease means that the loads will face under voltage issues. Every electrical component has some rated voltage range and they require more current in under voltage condition .This extra current supply means more heat generated which might affect equipment health. The unbalance currents also induces opposing flux on the transformer core, which leads to further reduction in voltage fig.1.

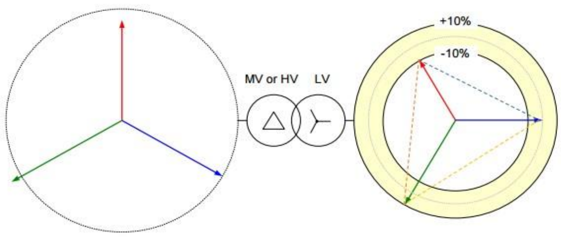

Fig. 1. Voltage imbalance due to unbalance loads.

C. Copper Losses:

The copper loss is calculated as $= I^2R$ .When the system is overloaded, a large amount of power is lost due to overheating. In balanced case, Power loss in three phase is given as

$$P_{balance} = 3I^2R \qquad (2)$$

In unbalance case, power loss is governed by the following formula:

$$P_{unbalance} = {I_r}^2R + {I_y}^2R + {I_b}^2R \qquad (3)$$

eq.(2) states the power loss when the system is balanced and eq.(3) is the power loss when system is unbalanced. Now extra power loss due to unbalance can be compared by subtracting eq.(3) from eq.(2):

$$P_{loss} = P_{unbalance} - P_{balance} \qquad (4)$$

This results in tremendous amount of power loss.

D. Transformer efficiency reduced:

The unbalance supply of current also contributes to overheating of transformers. The unsymmetrical distribution of current leads to extra hysteresis and eddy losses in the transformer's core. Continuous unbalance causes the shortening of the life of transformers.

E. Malfunctioning of motor:

In the balanced system, three phase motor is supplied with all 3 three phases at the stator which combines to give an effect of rotating magnetic field. However, when the voltage of the three phases are different, a negative flux sequence exist along with positive and neutral flux patterns. Negative flux produces an opposing torque hampering the rotor motion, whereas neutral flux produces heat in the three phase motors.

III. PROPOSED APPROACH

The paper presents a scheme for the automatic monitoring of phase unbalance currents, and eliminating them if the current in the neutral wire exceeds the level set by the utility company. As shown in fig.2, it is composed of slave units placed near the loads end and a master unit centrally placed near the transformer. The slave unit measures the load currents by using current sensing device and transfers each individual load values to the master unit through a communication channel. On detecting current unbalance, the master unit executes an

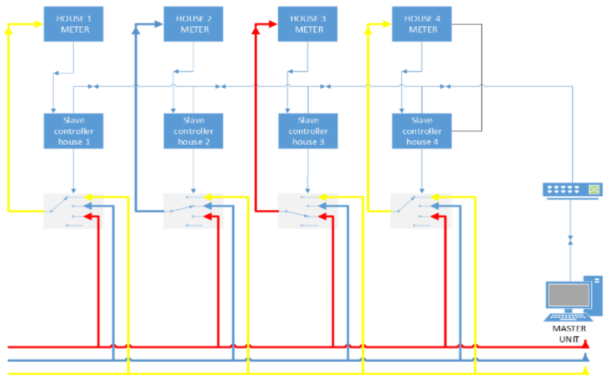

Fig. 2. Proposed scheme

efficient algorithm and as a result, it produces a scheme of possible phases for each individual load. The phases are then swapped accordingly. This results in uniform distribution of current in all three phase, hence eliminating the neutral current flow. This provides a novel solution to the aforementioned problems. The switching module is further elaborated in fig.3. Here triac is used to connect all three phases with the load. "*Break before make*" strategy is applied to ensure that two triacs are not on at the same time.

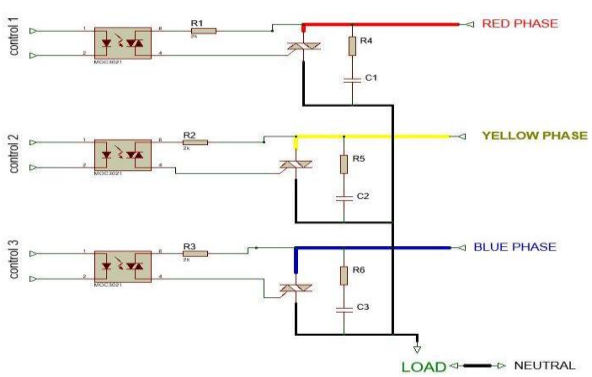

Fig. 3.Triac based switching

A. Algorithm:

The algorithm is designed in a way to solve the phase overloading issue by physically transferring loads among phases.

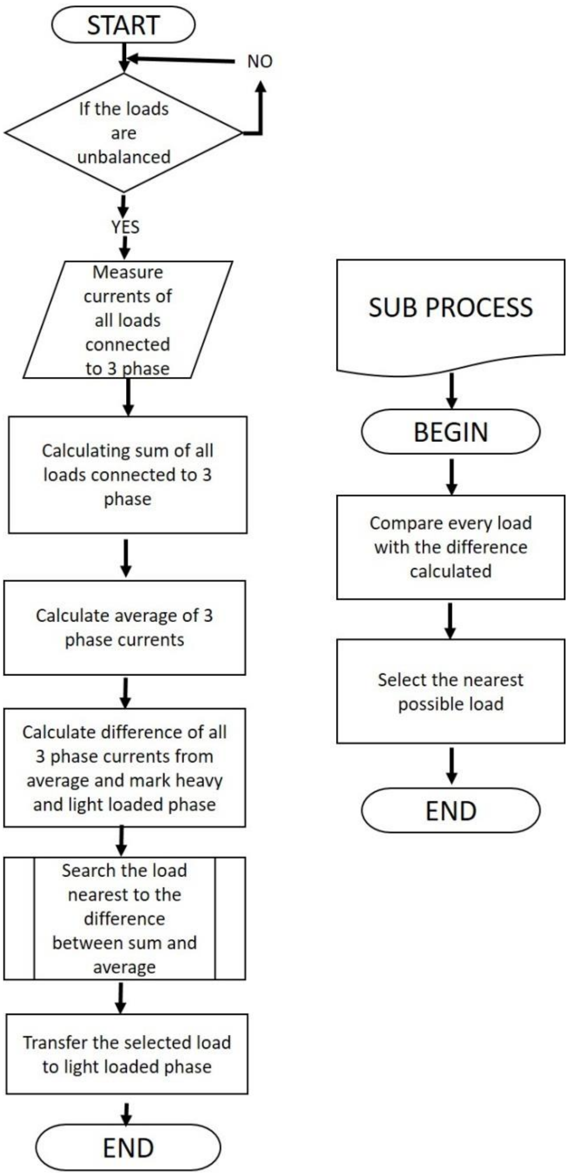

Fig. 4. Flowchart

The steps are as follows:

Step 1: Use current through the neutral wire as an indication of unbalance.

Step 2: Set the permissible limit of neutral current. If its magnitude is greater, give proceeding command. If it is lesser, wait until it becomes unbalance again.

Step 3: Measure the current values of each node and transmit it to the main controller.

Step 4: Use current of nodes to calculate an average current.

$$I_{avg} = \frac{I_a+I_b+I_C}{3} \qquad (5)$$

The average current is the ideal current which should ideally flow through each phase.

Step 5: It is imperative to mark the heavy and lightly loaded phase. Mark them after calculating the deviation of each phase current from the average current.

Step 6: Select the load from the heavy loaded phase whose current value is closest to the amount of current which is to be transferred.

Step 7: Trigger the triac of the selected load to swap its phase.

Step 8: The steps are repeated until the phase overloading is reduced to an acceptable limit.

B. Simulation Results*:*

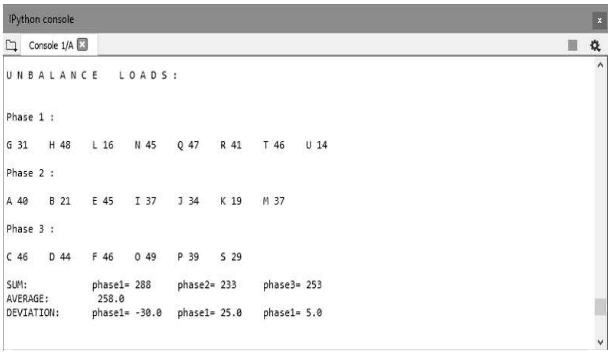

Fig. 5. Before balancing

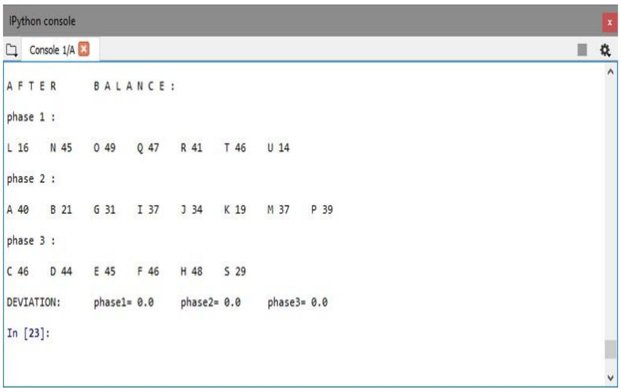

Fig. 6. After balancing

IV. SWITCHING MECHANISM

The most challenging factor is to regulate the efficient switching of loads from one phase to another. The switching period is often marred with an inrush current in case of inductive load. By the application of Laplace transformation on the ohms law equation $v = iR + L\frac{di}{dt}$.

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

Here, $\omega = \frac{L}{R}$ and $\varphi = \tan^{-1}\frac{\omega L}{R}$

This equation reveals the cases that can cause a high inrush current during the switching phase. Three different switching strategies are considered in the paper:

- Random Switching Strategy
- Zero Crossing Switching Strategy
- Pie Switching Strategy

A. Random Switching:

The loads are switched on instantly as the signals are applied without bringing the phases of the loads into consideration during switching. The switching off of the loads is ensured at the zero level of current Waveform. This method is not suitable for switching as it results in huge inrush currents as from equation 6.

B. Zero Crossing Strategy:

In this method, the loads are cut off from one phase at zero crossing of current and subsequent opening with a different phase is ensured at a zero crossing of voltage waveform. Special zero crossing circuit is used for this mechanism. This is far better than random crossing strategy.

We are using this as it reduces inrush current to considerable level compared to random crossing strategy and it’s much safer for the devices.

Consider a case of R-L load having R=36.6ohm and L=0.064H .Now with random and zero switching considering equation 6 we have,

Table 1, Inrush current with respect to switching angle

Angle of switching	Inrush current
0°	3.68A
5°	3.11 A
45°	2 A
60°	3.67A
90°	6.37 A
120 °	7.36 A
150 °	6.37 A
180 °	3.63

It is clearly obvious from this table that zero crossing strategy is far better than random switching strategy for switching among phases.

C. Phi Switching Strategy:

Phi switching strategy is considered as the most feasible solution to the said problem. This strategy is also used in Aircrafts to ensure load balancing [12]. According to this strategy, phase angle “φ” of the load is calculated and the loads are switched from one phase to another at $V_{in} = V \sin \varphi$. So as $\varphi = \varphi_0$ in this case and from eq.(6) it clearly shows that inrush current or DC Offset current is eliminated in this case.This is the best strategy for switching the R-L load from one phase to another and will be our future approach.

V. CONCLUSION

Load balancing has always been a problem at the low voltage distribution end, for that an efficient phase balancing method is explicitly described in the paper. An algorithm is presented which is capable of generating load balancing scheme at a low computation time. Phase swapping circuit is also designed and different switching schemes are discussed which can reduce the inrush current during switching period.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] Robert Arthur, R. A. Shanahan, ”Neutral Currents in Three Phase Wye Systems”, Square D Company,1995.

[2] A. B. Knolseisen, J. Coelho, S. F. Mayerle, F. J. S. Pimentel and R. H.Guembarovski, ”A Model for the Improvement of Load Balancing in Secondary Networks”, IEEE Bologna Power Tech conference, June 23- 26, 2003, Bologna, Italy.

[3] S. Patel, ”Power Load Balancing Using Fuzzy Logic”, MSC thesis, California State University, Sacramento, 2010. S. Patel, "Power Load Balancing Using Fuzzy Logic", MSC thesis, California State University, Sacramento, 2010.

[4] Winter G., J. Periaux, M. Galan. "Genetic Algorithms in Engineering and Computer Science", John Wiley & Sons Ltd., 1995..

[5] Civanlar, Seyhan, et al. "Distribution Feeder Reconfiguration for Loss Reduction." *IEEE Transactions on Power Delivery* 3.3 (1988): 1217-1223.

[6] M. Gendreau, “An Introduction to Tabu Search”, Département d´informatique et de recherche opérationnelle, University of Montreal, Montreal, Jul 2002.

[7] A. Merlin and H. Back, “Search for a Minimal-Loss Operating Spanning Tree Configuration in an Urban Power Distribution System”, Proceedings of the 5th Power System Computation Conference, Campbridge, U.K., pp. 1-18, 1975.

[8] Von Jouanne, Annette, and Basudeb Banerjee. "Assessment of Voltage Unbalance." *IEEE transactions on power delivery* (2001): 782-790.

[9] M.W. Siti, A.A. Jimoh and D.V. Nicolae, “Feeder’s Load Balancing Using an Expert System”, European Conference on Power Electronics and Applications, Sep 2005.

[10] M.E.Baran and F. F.Wu, “Network reconfiguration in distribution systems for loss reduction and load balancing,” IEEE Trans. Power Del., vol. 7, no. 2,

pp. 1401–1407, Apr. 1989.

[11] Egwaile J. O, Onohaebi S.O, Ike S.A, "Evaluation of Distribution System Losses Due To Unbalanced Load in Transformers. A Case Study Of Guinness 15MVA, 33/11KV, Injection Substation And Its Associated 11/0.415 kV Transformers In Benin City, Nigeria, Department of Electrical/Electronic Engineering, University of Benin, Benin City", Nigeria.*International Journal of Engineering Research & Technology*Vol.2 - Issue 3 (March - 2013)

[12] Michael Terrde, Trung Do Thanh, Jens Lemke, "Innovative strategies for protecting power semiconductor switches for phase balancing and feeder balancing in aircraft, IEEE Compatibility and Power Electronics (CPE), 2013.