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Stochastic Approach of Voltage Optimization to Maximize Power Saving in A Building

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Abstract

This paper presents the energy saving analysis by using voltage optimization technique, via Stochastic approach in an unbalanced three phase building distribution system. The voltage optimization technique is performed by installing voltage regulator units connected in series with every incoming transformer with optimize tap setting, via Stochastic approach using MATLAB® and SIMULINK® software. The results show a substantial improvement in terms of overall cost of energy consumption compared to the base case.

Keywords: *Stochastic optimization, building distribution system, voltage regulator, energy saving*

1. Introduction

In today's world, the need for more energy seems to be increasing rapidly especially on developing countries such as Malaysia. Both households and industries require large amounts of energy for about 20% of the overall world-wide energy consumption [1], with an increasing trend over time. On that basis, energy consumption has been proved to increase dramatically due to the world economic development. Hence, a more practical and robust approach need to be address to solve the ever-increasing energy demand, which includes new energy efficiency technologies approach.

Energy efficiency approach have become a quite popular trend in this era and proves to deliver a more practical solutions regarding energy related problems. However, the energy efficiency technologies such as renewable energy is not an affordable solution that developing country need to implement due to the fact that higher capital investment needed for the said technologies [2]. Hence, an affordable energy efficiency technology called voltage optimization technique will be applied, offering potential benefits in terms of power saving, reliability and total cost of ownership [3].

In electrical building system, certain electrical appliances and machines operate more efficiently when the supply voltage is regulated and stabilized [4]. If low-voltage electrical equipment is operating at higher than its designated operating voltage, unnecessary energy will be consumed and the equipment may become overheat. Hence, to cater energy efficiency problems especially in term of improvement in energy consumption for a distribution system of a building, voltage optimization is proposed.

Intrinsically, voltage optimization is an energy saving technology that is used to regulate, clean and condition the incoming power supply in order to reduce the voltage supplied to the optimum level for the on-site electrical equipment and appliances [5]. However, the variation of voltage magnitude for electrical building system must obey the standard tolerance imposed by the Energy Commission of Malaysia which is -6% to +10% for the nominal voltage magnitude of 400V [6]. This voltage tolerance ensures all electrical equipment work safely within this range.

Voltage optimization technique such as voltage regulators will regulate the voltage according to standardized voltage level. This type of equipment will ensure that the voltage on the site is maintained at the desired level, irrespective of the changes in the grid supply voltage.

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Most electrical equipment is designed to operate with voltages within the standardized levels, hence most electrical equipment is supplied with a higher voltage than is required for satisfactory operation. This technology provides a desirable operating environment for electrical equipment and enables certain loads to operate at lower voltage level without violating the recommended voltage tolerance imposed by the Energy Commission of Malaysia. As an example, a 230V lamp operating at 240V typically consumes 9 percent more energy, yet has its expected lifetime reduced by around 45 percent. However, if the 230V lamp operating at exactly 230V, the energy consumption would be reduced significantly on a building having that type of lighting system. In addition, the reduction in term of voltage and energy consumption by electrical equipment will also reduce the operating temperature of the equipment, thus extending equipment lifetime, with a consequent reduction in maintenance costs.

2. Research Method

Since the tariff of electricity is based on real power consumption in kWh, the increment of electricity bills can be significantly increased if the electricity usage is not monitored thoroughly by consumers [7]. In this circumstances, controlling the voltage is the best option to reduce the real power consumption. Theoretically, the voltage magnitude of a building system can be manipulated by controlling the voltage regulator's tap setting located at the incoming transformer. Hence, the optimal voltage regulator's tap setting will be the main issue that needed to be solve without violating the constraint of voltage level, total harmonic distortion and power factor prescribed by the utility of Tenaga Nasional Berhad (TNB) and Energy Commission of Malaysia. Hence, the proposed technique of Stochastic approach is implemented to postulate the most optimize voltage regulator's tap setting in order to maximize energy saving. The most common tap setting available for voltage regulators in the market are shown in Table 1.

Table 1. Comparison between 4-steps Voltage Regulator's Tap Setting and 32-steps Voltage Regulator's Tap Setting

Tap setting of voltage regulator	Percentage of V_{rated}
4-steps	2.5% of V_{rated} for each step
32-steps	0.625% of V_{rated} for each step

2.1. Problem Formulation

The main purpose of voltage optimization through the implementation of voltage regulators in a building is to reduce the total power consumption in the system. The formulation of power saving utilized in this study as the crucial parameters for the optimization solution is given in equation (1).

$$P_{total\_save} = \sum_{m=1}^{n} P_{total\_line\_base_m} - \sum_{m=1}^{n} P_{total\_line\_after_m} \quad (1)$$

where, *m* and *n* is the feeder number and total number of feeder, respectively.

2.2 Methodology

The proposed Stochastic approach methodology randomly selected sizing for voltage regulators based on the repetitive process for every transformer in a building distribution system. Once the process of Stochastic approach is halted, analysis between the results of each selected voltage regulators sizing is performed.

a. Perform a three-phase unbalanced load flow solution for the original system using SIMULINK® software in order to obtain the base case value of total active power, P_{total_line} , using Equation (2).

$$P_{total\ line} = \sum_{m=1}^{n} P_{line_m} \quad (2)$$

b. Generate a matrix consisting of '1' and '0' in Equation (3) to represent the existences phase current at a riser indicating whether the riser is available or not-available, where the value of '1' indicates there is a current flowing through the phase of a riser which is connected with a load and vice-versa. The process is repeated for every transformer.

$$\mathrm{R_{x,\emptyset}} = \begin{cases} 1, \text{if } \mathrm{I_{R_{x,\emptyset}}} > 0 \\ 0, \text{if } \mathrm{I_{R_{x,\emptyset}}} = 0 \end{cases} \quad (3)$$

where, $\mathrm{I_{R_{x,\emptyset}}}$ represent the line current flowing through every phase, Ø, of a riser, x.

c. Generate randomly a set of voltage regulator's tap setting at every incoming transformer by using Equation (4).

$$\mathrm{V'_{r,\emptyset}} = \mathrm{V_{r,\emptyset}} \pm (\%\mathrm{VR_{tap}} \times \mathrm{V_{rated}}) \quad (4)$$

where, $\mathrm{V_{r,\emptyset}}$ represent the voltage magnitude at every phase, Ø, of a riser, x.

d. Use Equation (5) to install voltage regulators at every incoming transformer and perform load flow solution to obtain total active power, $\mathrm{P_{total\_line}}$.

$$\mathrm{VR_{rating}} = \sqrt{3} \times \mathrm{V_{rated}} \times \mathrm{I_{load}} \times 10\% \quad (5)$$

where, $\mathrm{V_{rated}}$ and $\mathrm{I_{load}}$ is the rated voltage and load current of the system, respectively.

e. Calculate total active power saving, $\mathrm{P_{total\_save}}$ by using equation (1). The total active power saving is determined by subtracting the summation of total active power at every incoming transformer for base case with the summation of total active power at every incoming transformer obtained after installing voltage regulators.

f. Repeat step b) to e) until maximum evaluation, hmax=100, and record important parameters such as voltage regulator's tap settings, total power savings, power factors, voltage magnitude, and total harmonic distortion at every incoming transformer for further analysis to determine the best voltage regulator's tap setting with respect to the maximum total power saving.

g. Halt the process of Stochastic method during which the maximum iteration, hmax is reached.

3. Results and Analysis

The proposed algorithm is tested in a three-phase unbalanced electrical building distribution system model. The voltage optimization is achieved through the implementation of voltage regulators connected in series with every incoming transformer of a building. Stochastic optimization algorithm is used to determine the best value for voltage regulator's tap setting with respect to the maximum total power saving.

The three phase unbalanced building distribution system is embedded with the total real and reactive power of 2,952.08*kW* and 1,705.62*kVar*, respectively. The test system is said to be unbalanced since there are several risers connected with only single or two phase load. The test system is operating at the nominal voltage of 415 *V*. However, it is contradictory with the existing voltage magnitude of 433 *V* measured at all of the secondary side of the incoming transformer. Indeed, most of electrical component can still operate within a certain tolerance above 415 *V*. However, a large voltage magnitude supplied to the load will cause to a higher energy consumption and vice-versa, since most of electrical loads in the building consists of voltage dependent type load such as motors without variable speed drive (VSD) controller and fluorescent lights with magnetic ballast. Hence, voltage optimization approach proves to be the best solution in order to reduce the cost of energy consumption, as presented in the results in Table 2.

Table 2 elucidates the result obtained from the Stochastic optimization (SO) process which consist of the total energy loss, cost of energy loss, and power factor. Table 2 also shows the results extracted from the unbalance load flow simulation incorporated with SO for voltage regulator's tap setting performed on the tested electrical building distribution system. It is perceived that best solution for optimal voltage optimization using Stochastic approach have shown the system draws a real and reactive power of 2480.24 *kW* and 1912.40 *kVar* for the consumption with the total real and reactive power losses of 2.65 *kW* and 1.24 *kVar*, respectively. The power consumption has been reduced by 471.84 *kW* compared to the base case condition without implementing the Stochastic approach for voltage regulator's tap setting.

Table 2. Results Comparison between Base Case and Voltage Optimization Implementation Via Stochastic Approach

System Parameters	Base Case	Voltage Optimization
Total cost of energy consumption (RM/year)	1,791,370.94	1,433,974.11
Total cost of energy losses (RM/year)	2,812.25	1,534.12
Total real power consumption (*kW*)	2,952.08	2,480.24
Total reactive power consumption (*kVar*)	1,705.62	1,912.40
Total real power loss (*kW*)	4.86	2.65
Total reactive power loss (*kVar*)	2.47	1.24
Maximum voltage magnitude ($V_{p\text{-}n}$)	253.44	252.68
Minimum voltage magnitude ($V_{p\text{-}n}$)	250.12	249.72
Average power factor (*pf)*	0.84	0.77
Maximum THD*v* (%)	3%	1%

Other than that, voltage optimization with Stochastic approach shown a significant reduction in term of total real and reactive power losses incurred in the system with about 45.47% and 49.79% reduction from the total real and reactive power drawn into the system, respectively. By assuming that the system operates at constant loading condition for 6 hours per day, 22 days in a month and 12 months in a year, the total cost of energy consumption and energy losses with voltage optimization of voltage regulators are RM 1,433,974.11 per year and RM 1,534.12 per year, respectively. This results explains that the saving obtained from voltage optimization with stochastic approach compared to base case condition is significant at RM 357, 396.83 total saving per year. The cost is calculated based on tariff (C1) given by the Tenaga Nasional Berhad (TNB) which is RM 0.365/*kWh* [6]. Based on Table 2, the maximum and minimum operating voltage magnitudes are 252.68 V*p-n* and 249.72 *Vp-n*, respectively. Thus, it is obvious that the operating voltage magnitude during the load flow condition comply with the tolerance prescribed by the Energy Commission of Malaysia. The power factor during the implementation of voltage regulators load flow solution is 0.77 *p.f* which is lower than the minimum power factor of 0.85 *p.f*. This implies that the lower power factor is compelling the load flow solution to draw excessive reactive power from grid. However, this problem can be mitigated by installing capacitor banks at the feeder or risers in order to reduce the amount of reactive power drawn from the grid as well as to improve power factor with the accordance of minimum requirement prescribed by TNB at 0.85 *p.f* for commercial building. The total harmonic distortion of voltage magnitude (*THDv*) of 1% is obtained from the load flow solution has been improved from 3% obtained from base case condition and comply with the *THDv* regulation below the limit of 5%.

4. Conclusion

Voltage optimization has been considered and proposed as a solution for energy consumption problems of the unbalanced three phase building distribution system. Voltage optimization through installation of voltage regulators in the test system using *MATLAB*® and *SIMULINK*® software have been implemented successfully, followed by the determination of total cost of energy consumption and energy losses of the system. The implementation of voltage regulator with the proper size proves to increases power saving per year while following the operational constraints within the specified limits. From the results, it is observed that the

SO for voltage optimization has succeeded with the maximum power saving shows a significant improvement compared to the base case. However, the lower value of power factor compared to base case when implementing voltage regulators to the test system need to be addressed for further case study.

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