Loss Minimization and Capacity Saving in Residential Networks - An AIT Case Study

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Abstract – *This paper opens up a novel technique of end-user based energy saving and loss reduction technique evolved from a energy audit study conducted in the residential dormitories of Asian Institute of Technology (AIT) Bangkok, Thailand. An automatically switched capacitor was connected to some of the residential socket plugs of each dormitory and analyzed the capacity saving and loss minimization. This study focused on the healthy conclusion that a substation and a DG of 500 kVA could able to be eliminated in terms of the capacity investment and there was also a marginal saving in the institute monthly electricity bill payment to the Provisional Electricity Authority of Thailand due to the reduction in network losses.*

Keywords – *distribution system, distributed generation, reactive power compensation, loss reduction, wind power generation.*

1. INTRODUCTION

The global demand for energy is increasing in an alarming pace. This sharp increase in world energy demand requires significant investment in network strengthening and loss Minimization, especially in the developing world [1]. Often the distribution system is the most vulnerable part of the electric supply chain network, being the most exposed to end-users. About 30 to 40 % of total investments in the electrical sector go to distribution systems, but nevertheless, they have not attained the technological efficiency in the same way as that of the generation and transmission systems [2].

The quality of the distribution system is measured in terms of the quality of the power served and the amount of losses incurred. Effective management of the distribution system results in loss reduction there by which DGs of less capacity can be used to supply the existing demand efficiently. Ideally, losses in an electric system should be around 3 to 6% [3]. In developed countries, it is not greater than 10%. However, in developing countries, the percentage of active power losses are around 20%; therefore, utilities in the electric sector are currently interested in reducing it, in order to be more competitive, since the electricity prices in deregulated markets are heavily dependent on the system losses.

Power loss minimization by various techniques have been explained by L.Ramesh et al. [4]. Power losses are divided into two categories, real power loss and reactive power loss. The resistance of lines causes the real power loss, while reactive power loss are produced due to the reactive elements. Normally, the real power loss draws more attention for the utilities, as it reduces the efficiency of transmitting energy to customers. The distribution network is the terminal stage of power system, ended by consumers. The main problem that are found in the distribution network is that, it is affected by both consumers and utilities. Consequently, controlling the reactive power and regulating the node voltages results in the reduction of power loss which has got a great concern by utilities.

Often the loss minimizations in the distribution networks are localized in the feeder side and numbers of techniques have been proposed. Peponis *et al.* [4] have developed a methodology for the optimal operation of distribution network. In this method loss minimization was obtained by the installation of shunt capacitors based on the reconfiguration of the network. Alternatively the concept of loss minimization has to be originated from the root itself; that is from the end user. Studies showed that the best locations for the installation of reactive power compensating devices are near to the load centre. [5]. A single VA saved in the consumer side multiples to several folds when it is taken through the substation level to generation level.

Deregulation and restructuring of the energy market and steady increasing costs of power production in many countries have put enormous pressure on the margins of the utilities. In order to improve the efficiency of the electrical system, and create further capacity, authorities began to implement incentives for power factor correction. Under these set up, electricity distributors must achieve certain minimum power factor or have to face penalties.

Power factor correction (PFC) has found widespread use in commercial applications, both within industrial facilities, office complexes and in the power distribution grid in close proximity to commercial clients. Nowadays, in some regions of the world, residential PFC also becoming more and more popular [5]. Mostly residential consumers are not that much bothered about power factor correction, since the metering in mainly in Kilowatt hour. A residential consumer often uses low power factor luminaries and

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other devices to exploit this opportunity. For this reason, a new solution is to explore the benefits of deploying PFC in the low voltage distribution networks as close to the consumer load premises as possible, in private residences, or in residential colonies have been suggested. AIT Campus residential complexes have been explored for this current investigation. In a residential set up like Asian Institute of Technology, which is the provider and distributor, these mechanisms of power correction and compensation seemed to be worthy enough. The main contributions of the paper are the following: (a) A novel technique of capacitor placement in any of the socket plug of residential dormitory have been proposed. (b) It so proved experimentally that a DG can be undersized or totally eliminated by suitable capacitor placement. (c) It was also proved mathematically that, there exists a conderable saving in the monthly electricity bill.

The paper has been organized as follows. In section 2, the concept of power factor and its importance have been presented. The methodology of work carried out was explained in section 3. Section 4 presented some interesting numerical results along with some discussions with regard to the capacitor selection and installation. Finally, conclusions and major contributions of the paper was summarized in section 5.

2. RESIDENTIAL POWER FACTOR & CORRECTION

The residential power factor is the ratio of percentage of electricity that's delivered to the house and used effectively, compared to what is wasted.

$$PF = \frac{kW}{KVA} \tag{1}$$

A unity (1.0) power factor means that all the electricity that's being delivered to the home is being used effectively for its purpose. However, most homes today have a power factor 77% or less. This means that 77% of the electricity that is coming through the meter is being used effectively; the remaining 23% is being wasted by the premise inductive load. With low power factor, the utility has to deliver more electricity to do the same work. However, the Power-Save unit increases that power factor in most cases to 0.97 or 0.98, thus increasing the effective use of electricity. The ratio of actual power to apparent power is usually expressed in percentage and is termed as power factor.

It has also been proved that, power factor imporvement also results in reduction in system losses.

Reduction of percentage active power Losses by installing the capacitor is given by

$$100 - 100\left[\frac{OriginalPowerFactor}{improvedPowerFactor}\right]^2 \tag{2}$$

In an electric power system, a load with low power factor draws more current than a load with a high power factor, for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipments. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor. By using a shunt capacitor, the apparent power and power factor can be corrected to any desired set value as per the phasor diagram given in Fig.1.

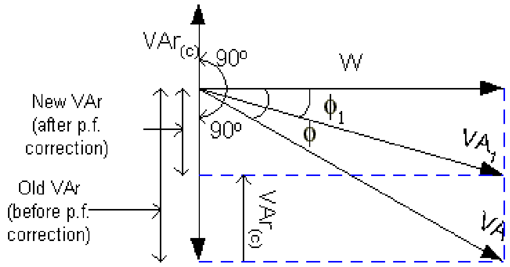

Fig. 1. Power factor correction phasor diagram.

3. METHODOLOGY

The project deals with the analysis of the power saving and cost minimization by connecting the residential power factor improving switching capacitor in the any of the socket plugs in the residential dormitories of AIT or are centrally connected in the energymeter terminals depending on the load consumption pattern of that residential dormotory. The project implementation consisted of the following stages: (a) load survey and load duration curve formulation, (b) capacitor sizing and installation (c) cost saving analysis.

3.1 Load survey and load duration curve

Load survey was conducted in typical categories of dormitories for their consumption pattern and the load duration curve were plotted. From the load duration curve, the timing of maximum demand and power factor were determined. Suitable capacitor and switching criterea was hence decided.

3.2 Capacitor selection and installation

The only obstacle for residential PFC was the lack of a suitable capacitor that are standardized for installation. Various types of residential power factor improvement capacitors are available in the market. The basic capacitor sizing calculation equation is given in equation(3).

$$C = \frac{\varepsilon A}{D} \tag{3}$$

3.3 Saving analysis

Assuming a suitable diversity factor, the daily and montly consumption saving can be calculated. Simlar is the case with the capacity saving.

4. RESULT AND DISCUSSION

AIT is a fully fledged and 100% residential, leading post graduate institute in Asia and having multicultural students and faculty from more than 50 countries. Their diversified taste and flavor reflected in their power consumption pattern also. The Institute is having various categories of residential and recreation facilities. Certain dormitories were meant for single accommodation and certain for the family level. Most of the single accommodation is having power equipments like refrigerator, toaster, rice cooker etc. The building, electrification systems and procedures were around 50 years old, as in where the condition when the institution was started. Each dormitory or two dormitory is having separate energy meter outside for amount billing and charging purpose.

Certain dormitories are having individual Air Conditioners (ACs) and are part of central air conditioning system. The cooling power requirement is also varying from floor to floor. In the top floor, more consumption in hot seasons was visible. The readings and analysis taken as a sample is for spring season, where moderate climatic conditions with less temperature as per the climatic conditions of Thailand As mentioned above the project was implemented in three different stages. Only fundamental frequency based analysis was considered. Also overcompensation due to capacitance effect was neglected and voltage was assumed to be maintained within the rated value.

4.1 Load survey and load duration curve

The load duration curve varied with the type and nature of the dormitory. For married units the load duration curve seemed to be continuous and the high value of load in certain dormitories indicated the steady air conditioning demand. The load duration curve formulated for a typical categories of dormitories and varied from dormitory to dormitory as given in Fig. 2 to Fig. 11. The central air condition affect was not taken to consideration. The various categories of dormotories and their features with maximum demand were given in Table 1. The various types of equipements and their specifications that are used in used in the dormnotories are given in table 2 of appendix.

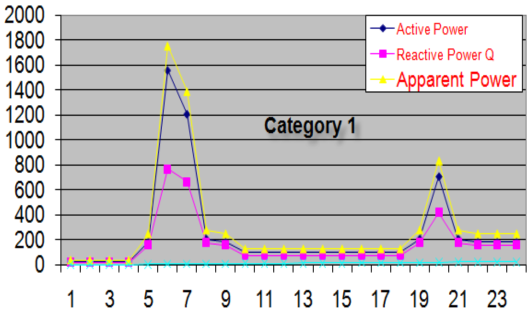

Fig. 2. Typical load duration curves catagory 1.

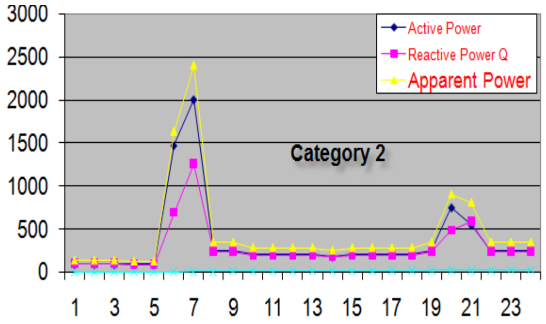

Fig. 3. Typical load duration curves catagory 2.

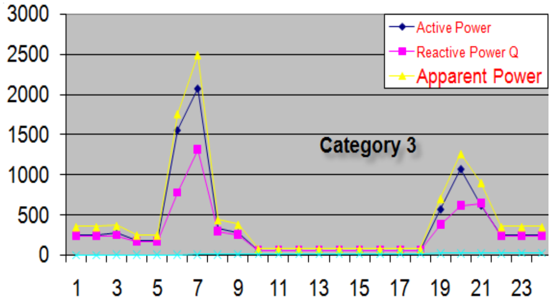

Fig. 4. Typical load duration curves catagory 3

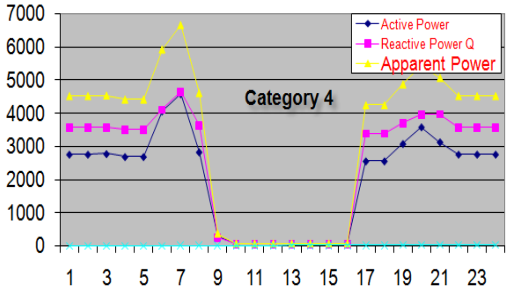

Fig. 5. Typical load duration curves catagory 4.

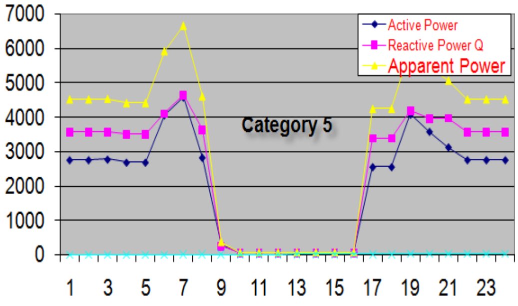

Fig. 6. Typical load duration curves catagory 5.

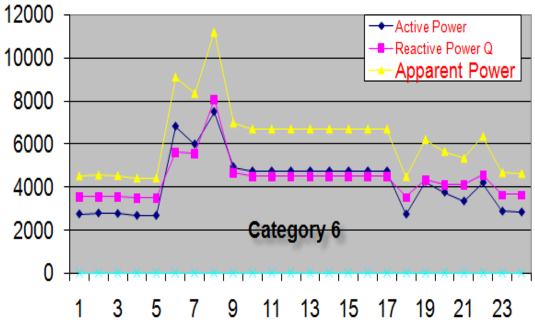

Fig. 7. Typical load duration curves catagory 6.

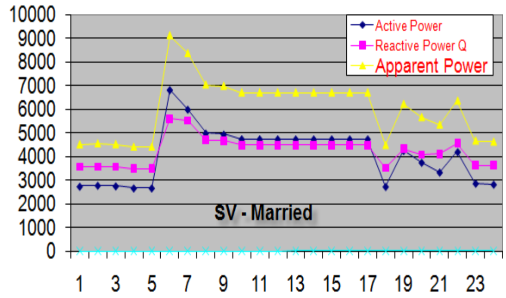

Fig. 8. Typical load duration curves SV-maried.

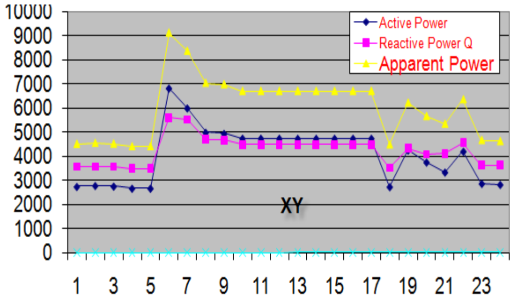

Fig. 9. Typical load duration curves XY

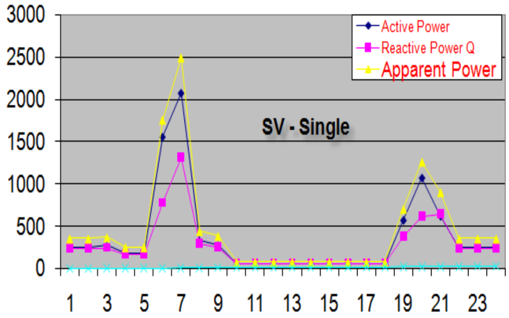

Fig. 10. Typical load duration curves SV-single.

All analysis were carried out by using Fluke 41 power analyzer as given in the fig 12.

Fig. 11. Fluke Power Analyzer under Measurement

4.2 Capacitor sizing and installation

Two residential power capacitors for testing were provided by Epcos Power Capacitor Company, Germany and is given pictorically in Fig. 13. and the typical capacitor specification is shown in Table 3 of Appendix

Fig. 12. The epcos residential power factor improvement capacitor

Two different schemes of capacitor connection were used , as given in Fig. 13. For small residential dormitories, where there was an identified localized low power factor high power rated load, the compensation have been provided in the nearby socket plug. In big dormitories, where a number of ACs and other central load have been connected, the compensation was provided centrally, near the energymeter. The capacitor was switched on when the power factor is below 0.8 and switched off when it reached about 0.97.

(a) Capacitor connected in meter box

(b) Capacitor connected in socket plug

Fig. 13. Various type of capacitor connection.

In most cases the capacitors were centrally connected for compensation in the meter box and were switched on and off manually for testing based on the load on and off switching. If the correct capacitor was not available, corresponding suitable series parallel combination were used to achieve the same and in all cases same type of capacitors were emboyed.

3.3 Saving analysis

The reductions in kVAR were translated into a reduction in generation requirements and reduction in the amount of capacity required in the system. Improving system capacity resulted in less wear and tear on the system. It is difficult, however, to determine exactly what the savings are. The cost of the units is approximately $75/each. There are a number of ways to estimate what the savings for industrial customers, adding capacitance reduces utility penalties and frees up capacity within their system, often reducing the need for new or larger transformers. Although there are no billing incentives to the end use residential customer by correcting power factor the benefits of free capacitance to the utility is similar to that of the industrial customer.

In the residential complex of AIT, the installation of capacitor in each of the dormitories could able to save a DG and a transformer and there by which, one of the associated mini substation could be avoided. When compared to the cost of the substation generator &

transformer, the cost of the capacitor associated equipment is very less. The life expectancy of the capacitor is around up to 100,000 hours which results in a very short pay-back-time of investment. Normally the payback period for the capacitor installation is 2 years and moreover the advantages of residential PFC go far beyond the cost savings.

The Table 1 showed the capacity saving and unit analysis of the AIT residential energy audit study. From the table , it is quite clear that, 782 kVA was saved in terms of capacity and daily unit saving of 15units per day. Any how the saving is approximately the cost of a DG, a mini substation and the associated transformer and equipments. The daily unit saving was calculated based on the assumption that the power factor saving equipment was working on the daily average load for at least 10 minutes in a day.

Table 1. Saving Calculation.

Category	Type	Installed Capacity Saving (kVA)	Daily Saving due to power loss Reduction (kWh)
1	A	2.13	0.05
	B	2.13	0.05
	C	2.13	0.05
	D	1.77	0.05
	F	1.77	0.05
	G	1.77	0.05
	H	2.13	0.05
2	E	3.73	0.09
	J	4.48	0.10
	K	3.73	0.09
4	L	78.12	1.34
	Q	78.12	1.34
6	P	34.47	1.08
3	M	3.93	0.09
	N	6.07	0.14
	R	6.07	0.14
	S	3.93	0.09
5	T	78.35	1.36
	U	32.26	0.56
	V	78.35	1.36
	W	32.26	0.56
XY	X Single	94.42	1.81
	Y Single	94.42	1.81
SV - Single	Village I	5.36	0.13
	Village II	7.50	0.18
	Village III	6.97	0.16
SV - Married	Village I	36.32	0.70
	Village II	21.79	0.42
	Village III	58.11	1.12
		782.60	15.04

Table 2. AIT dormitory equipment specifications.

Sl	Equipment	P(Watts)	PF
1	Air Conditioner (AC)	2500	0.6
2	Water Heater	2000	0.9
3	Television	250	0.95
4	Motor	1000	0.6
5	Refrigerator	500	0.65
6	Tube Light Fittings - 4Ft	47	0.79
7	Tube Light Fittings - 2Ft	23.5	0.79
8	Normal Incandescent Lamp	40	1
9	CFL	16	0.6
10	Night Lamp	15	0.95

11	Fans	30	0.83
12	Computers	85	0.7
13	Microwave Ovan	1000	0.65
14	Washing Machine	750	0.6
15	Mixer/Blender	100	0.7
16	Iron Box	750	0.95
17	Music Player	100	0.8
18	DVD Player	75	0.7
19	Cooking Heater	1000	0.9

Table 3. Typical residential capacitor specification

Dielectric	Polypropylene film (Extra thick)
Rated voltage	400 V (application voltage 127 V to 400 V)
Capacitance	5 to 33 µF (Normally)
Reactive	0.25 to 1.66 kvar
Frequency	50 / 60 Hz
Diameter	40 mm
Height	70 to 105 mm

5. CONCLUSION

Energy providers are coming more and more and the competition between them are growing day by day. There is not only a demand for price decrease, but also for more power quality and efficiency. The achievement of a minimum power factor can be encouraged by authorities. The AIT model can be used as a model by other type of institutions and organizations.

Now very cute, capable and efficient residential power capacitors are available in the markets. In order to compete in the electricity market, it is necessary to utilize the novel technologies and innovative products today to fulfil the energy requirements of tomorrow. Power Factor Compensation also helps to considerably improve the voltage profile in the network.

NOMENCLATURE

P	Active power
Q	Reactive power
C	Capacitance in Farads
A	Area of plate in square meter
D	Distance between plate in meter
ε	Permittivity of pielectric
DG	Distributed Generation

REFERENCES

[1] Finfacts Team, 2009: World energy consumption projected to rise 44% from 2006 to 2030; Carbon emissions to jump more than 39% without new policies**,** *International Energy Outlook 2009*, May 29, from the World Wide Web: http://www.finfacts.ie/irishfinancenews/article_1016796.shtml

[2] L.Ramesh, S.P.Chowdhury, S.Chowdhury, A.A.Natarajan, C.T.Gaunt, 2009. Minimization of Power Loss in Distribution Networks by Different Techniques. *International Journal of Electrical Power and Energy Systems Engineering* 2:1

[3] G. J. Peponis, M. P. Papadopoulos, and N. D. Hatziargyriou, 1996. Optimal operation of distribution networks, IEEE *Trans. Power Syst., vol. 11*,*no. 1*, pp. 59–67, Feb.

[4] Whitby Hydro Energy Services Corp, 2005. Report of the Power Factor Correction at the Residential Level – Pilot Project: *Report to the LDC Tomorrow Fund*, UK , September 12.

[5] Electrocomp, 2006. Power capacitors for residential power factor correction. *DATAWEEK Electronics & Communications Technology*, 17 May, from the World Wide Web: *http://www.dataweek.co.za/new-s.aspx?pklNewsId=21088&pklCategoryID=45*

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