An approach for loss minimization and capacity savings in residential microgrid networks in Oman

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ABSTRACT

In this paper, an approach for end-user-based energy saving and loss reduction technique in residential networks has been proposed. The proposed approach is applied to an Oman case study of community microgrid networks by connecting automatically switched capacitors to improve power factor and analyzed for capacity saving and loss minimization. The proposed approach can reduce the cost of electrical bills in the total community microgrid by minimizing losses and the capacity investment cost saving of all equipments in the transmission and distribution line from the generation to the end user. In addition, this study focuses on the healthy conclusion that average kVA capacity could be saved to an extent of 12.22% and in economic terms, approximately USD 3.68 per hour in the microgrid. This proposed technique can be implemented as a model community project for other similar residential community systems.

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1. INTRODUCTION

Global energy demand is increasing at an alarming pace. To meet the demand, electricity can be managed either supply side or demand side. In demand side, distribution system requires significant network strengthening and loss minimization investment, especially in the developing world [1], [2]. The most vulnerable part of the electric power supply chain network is the distribution system, being the most exposed to end-users. Roughly around 30 to 40 % of electrical sector investments are in distribution systems.

The distribution segment has yet to attain technological efficiency, like the generation and transmission systems [3]. The performance of radial distribution system could be enhanced by maintaining the appropriate integration of microgrid [4]. The quality of the distribution system is measured in terms of the quality of the power served and the percentage of losses incurred. Effective distribution system management results in reduced losses, and distributed generation (DG) with a smaller capacity can efficiently supply the existing demand to reduce these losses. Losses in an electric system should be around 3 to 6% [5], [6]. Power loss minimization by various techniques has been explained by several scholars [7], [8].

One of the main issues of the distribution network is that it is one which is most affected by consumers and utilities. The loss minimizations in the distribution networks are mostly localized on the feeder side. The unit commitment is an optimization problem used to find out the least cost dispatch in microgrid [9]. In past, several techniques have been proposed by the scholars [10], [11], have developed the optimal distribution network operation methodology [12]. In this method, the concept of nloss minimization was obtained by installing shunt capacitors based on the reconfiguration of the network. Alternatively, the loss minimization concept has to be originated from the root itself, that is, from the end user. One of the methods for improving the distribution system is to maintain the reactive power balance for which reactive compensating devices can be installed. The studies showed that the best locations for installing reactive power compensating devices are near the load centers [13], [14].

A single volt-ampere (VA) saved on the consumer side multiples to several folds when taken from the substation to the generation level [15]. The deregulation and restructuring of the energy market and the steadily increasing costs of power production in many countries have put enormous pressure on the utilities' margins [16], [17]. To improve electrical system efficiency and create additional capacity, distribution company authorities began to implement incentives for power factor correction. Under this setup, electricity distributors must achieve a certain minimum power factor or face penalties [18], [19]. Power factor correction (PFC) has widespread relevance in office complexes, industrial facilities, and the power distribution grid near commercial clients. In some regions of the world, residential PFC is also becoming more and more popular [20], [21]. Mostly the residential consumers are not bothered by PFC since the metering is mainly in Kilowatt-hour (kWh). Often low-power factor luminaries are used by the residential consumer to exploit the opportunity. For this reason, a new solution has been suggested 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 residential colonies to form a community microgrid [22], [23]. Residential apartments and villas near University of Technology and Applied Sciences (UTAS), Suhar campus have been explored. In a community microgrid, which is power provider and distributor, these power correction and compensation mechanisms seemed to be worthy enough to investigate the outcomes of the work.

The novel objective of this work is to integrate the concept of microgrid for diminution of energy loss and apparent power capacity saving at the end users. In this paper an approach for loss minimization and capacity saving in residential micro-grid network has been discussed. The paper consists of five sections. The background of loss minimization has reviewed in section 1. The methodology and procedure of power factor correction in distribution network has been described in section 2 and 3 respectively. The results and discussion are included in section 4 while paper has concluded in section 5.

2. METHOD

The residential power factor (PF) is the ratio of the percentage of the electricity that's delivered to the house and used effectively, compared to what is wasted [24]. It is expressed by (1).

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

In power terms, the PF is a ratio of real power to apparent power. The unity PF of a dwelling means that all the electricity supplied to house is being used effectively for its intended purpose. However, most homes today have a power factor of 77% or less [18]. The meter effectively uses 77% of the power. The remaining 23% is wasted due to building inductive loads. If the PF is low, the power company must supply more current to do the same work. However, power-saving units often increase this PF to 0.97 or 0.98, thus increasing the effective use of power.

The ratio of real power (measured in, kW) to apparent power (measured in, kVA) is usually expressed as a percentage. Improving the power factor (PF_{imp}) has also proven to reduce the system losses. The percentage reduction in active power loss (% P_{loss}) [25] due to the installation of capacitors is determined by the (2).

$$\%P_{loss} = 100 - 100\left[\frac{PF}{PF_{imp}}\right]^2 \tag{2}$$

In a power system, a load with a lower PF draws more current than a load with a higher PF factor when transmitting the same active power. Higher currents increase energy losses in distribution systems, requiring larger cables and other equipment. Due to the cost of large equipment and wasted energy, utilities typically charge higher rates to end-users, having lower PFs. It can be seen from phasor diagram in Figure 1, a shunt capacitor can correct the apparent power and PF in any setting. The stage wise project implementation flow chart is given in Figure 2.

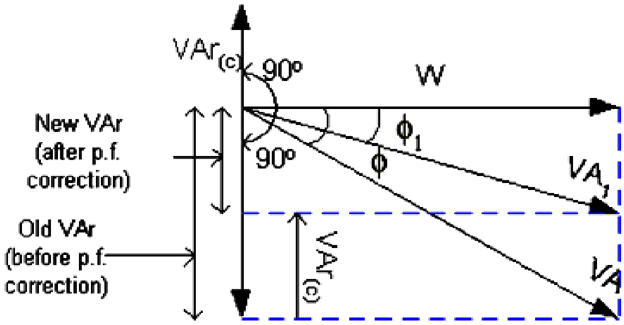

Figure 1. PF correction – phasor diagram

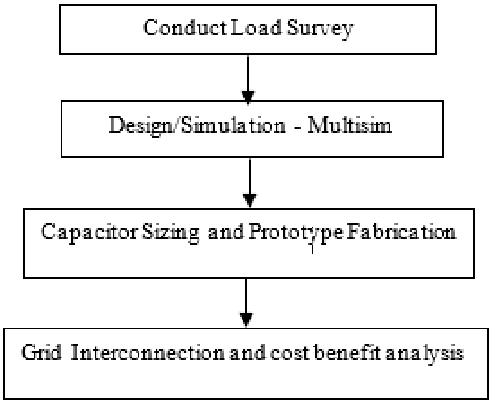

Figure 2. Project implementation stages

3. PROCEDURE

This project work deals with the analysis of power savings and cost minimization by connecting the residential power factor improving switching capacitors in the residences in Saud Bhawan Residential Community in Suhar, Sultanate of Oman which consists of 437 apartments, classic and premium villas. The work was carried out in four stages as given below.

Initially the load survey was conducted in various categories of Accomodation as given in the Table 1. Then the system simulation was conducted in multisim environment and the hardware was tested in various residences by interfacing with the grid in the main distribution board of each residence, apartments and villas. The capacitor is selected for various types of residences as given in Table 1 and is is switched automatically based on the residential loading pattern. The design calculations are carried out as per the load survey conducted and as per the load duration curve given in Figures 3-8. The Audrino driven hardware circuit automatically calculates the powerfactor of the load and the switches the capacitor as per the loading condition.

Table 1. Residence types in Saud Bhawan, Palm Gardens, Suhar

Category code	Type of housing	No. of apartments in a block	No. of blocks	Total apartment/villa	Connected load of each apartment/villa
2BHK48X3 – 2 BHK – 48X3	2 Bedroom Hall Kitchen Apartment	48	3	144	5087
3BHK24X6 - 3 BHK – 24X6	3 Bedroom Hall Kitchen Apartment	24	6	144	8863
3BHKV76 – Classic Villas	3 Bedroom Classic Villa	76	NA	76	11286
4BHKV73 – Premium Villas	3 Bedroom Premium Villa	73	NA	73	16317.5
Total			437		Residences

3.1. Load survey and load duration curve

The load survey was conducted in residences as per the details given in in Tables 1 and 2 respectively. Table 2 consists of various types of loads that are available in various as given in Table 1. The consumption pattern and the load duration curves for different categories of apartments and villas were plotted. A typical load duration curve for 2BHK48X3 types of apartments is shown in Figure 3. From the load duration curve, the timing of maximum demand and PF were determined. Suitable capacitor and switching criteria were hence decided.

Table 2. Typical load specifications

Sl. No.	Equipment	P Watts	PF	S kVA	Q kVAR	Remarks
1.	Air Conditioner (AC)	2500	0.6	4167	3133	Typical 1.5Ton Split Air Conditioner
2.	Water Heater	2000	0.9	2222	969	Typical Home Purpose 15- 20 Litre Heater
3.	Television	250	0.95	263	82	29 inch flat
4.	Motor	1000	0.6	1667	1333	1HP
5.	Refrigerator	500	0.65	769	585	165 Litre; Load should be adjusted for a maximum period of 5 Hrs in aday
6.	Tube Light Fittings – 4Ft	47	0.79	59	36	
7.	Tube Light Fittings – 2Ft	23.5	0.79	30	18	
8.	Normal Incandesent Lamp	40	1	40	0	
9.	CFL	16	0.6	27	21	16 Watts
10.	Night Lamp	15	0.95	16	5	
11.	Fans	30	0.83	36	20	Normal Ceiling Fan
12.	Computers	85	0.7	121	87	
13.	Microwave Ovan	1000	0.65	1538	1169	
14.	Washing Machine	750	0.6	1250	1000	
15.	Mixer/Blender	100	0.7	143	102	
16.	Iron Box	750	0.95	789	247	
17.	Music Player	100	0.8	125	75	
18.	DVD Player	75	0.7	107	77	
19.	Cooking Heater	1000	0.9	1111	484	
20.	Other Device 2	0	1	0	0	

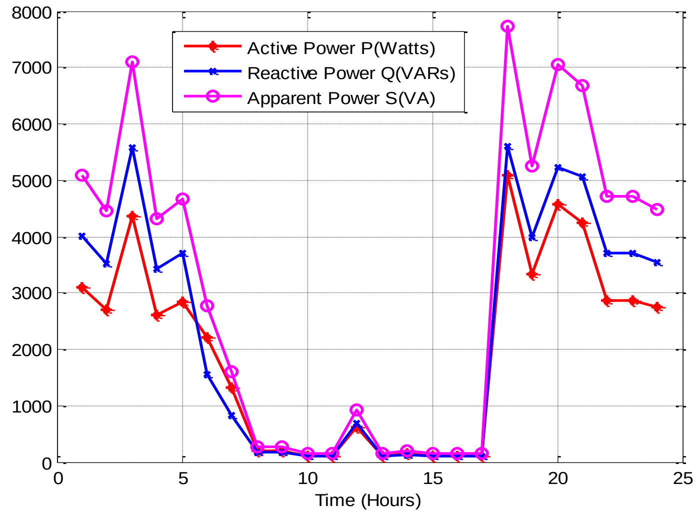

Figure 3. Load duration curve 2BHK48X3

3.2. Capacitor selection and installation

Even though various types of residential PF improvement capacitors are available in the market, one of the main obstacles for residential PFC is the availability of suitable power factor correction capacitors that are standardized for installation. The basic sizing calculation of capacitors is given by (3).

$$C = \frac{\varepsilon A}{d} \quad (3)$$

4. RESULT AND DISCUSSION

From the load survey and load duration curve, the load shifting pattern was obtained. The hardware circuit was designed using multisim software and is connected to Audrino Uno which formulates the actual switching strategy and gives control signal to relay for connecting the capacitor.

4.1. Hardware implementation

The components of the complete system are shown in Figure 4. The hardware includes a PZEM004T AC communication module, which is primarily used for measuring AC voltage, current, active power, frequency, power factor, and active energy. This module does not have a display. The Arduino Uno platform is used to manage the entire system and collect measurements from the PZEM004T, Table 3 shows the list of components used in the designed hardware.

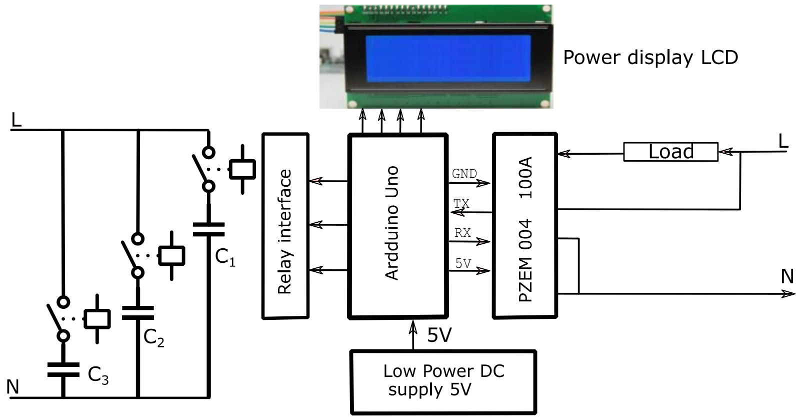

Figure 4. Schematic diagram of hardware components

Table 3. List of components used in the designed hardware

Parameter	Description	Value
PZEM004T AC Communication Module	Measures AC voltage, current, active power, frequency, power factor, and energy	-
Arduino Uno	Microcontroller used to manage system	-
Capacitor Banks	Used for power factor improvement	Various (switchable)
LCD Display Module	Displays measurements	-
Target Power Factor	Target power factor after capacitor installation	0.90
Inductive load	Single phase induction motor	1.5Hp

These measurements are then displayed on an LCD display module. The microcontroller collects the power factor measurement and, based on the measured value, connects capacitor banks to the supply input. This implemented hardware ensures that the power factor is always greater than 0.9 in all cases. The complete hardware components are shown in Figure 5, where different capacitor values are connected.

4.2. Saving analysis

The residential PF is an important index of electricity that is delivered to the house and used effectively, compared to what is wasted. The unity PF is indicating that all the electricity that is being delivered to the house is being used effectively for its purpose. However, most of the dwellings today have a lower PF (77% or less) due to several inductive loads. 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 PF, the utility has to deliver more electricity to do the same work. However, the use of power saver unit increases the power factor in most cases to 0.90 or 0.92 by storing the electricity in the capacitors and releases it in a smooth output without any surges. Thus, it is increasing the effective use of electricity. It has also been proved that PF improvement also results in the reduction in system losses.

From the load data of 437 dwellings, it has been observed that some variation in nature of the load patterns is due to difference in power consumption of individual house. The active, reactive and apparent powers for different types of apartments are shown in Figures 3 and 6 while for villas it is shown in Figures 7 and 8. It was observed that the amount of power consumption is considerably higher for villas than the apartments.

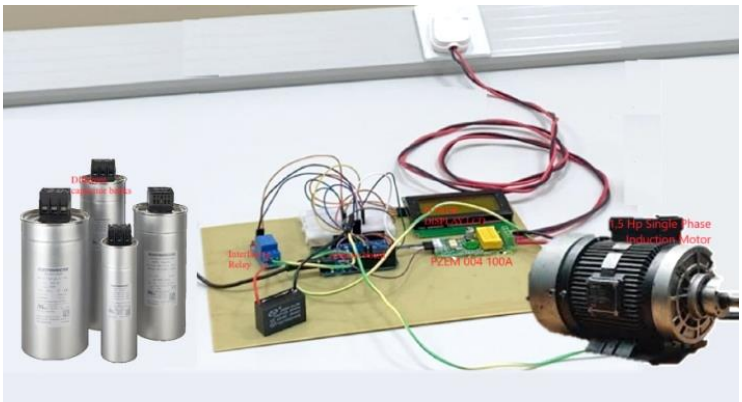

Figure 5. Prototype testing

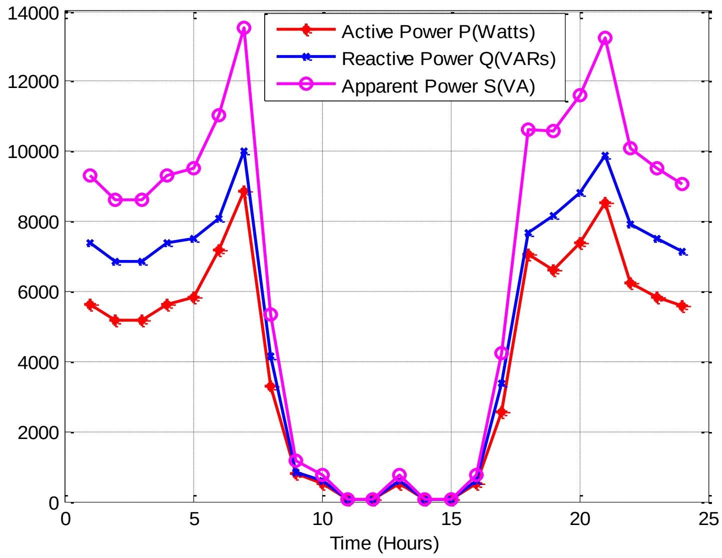

Figure 6. Load duration curve 3BHK24X6

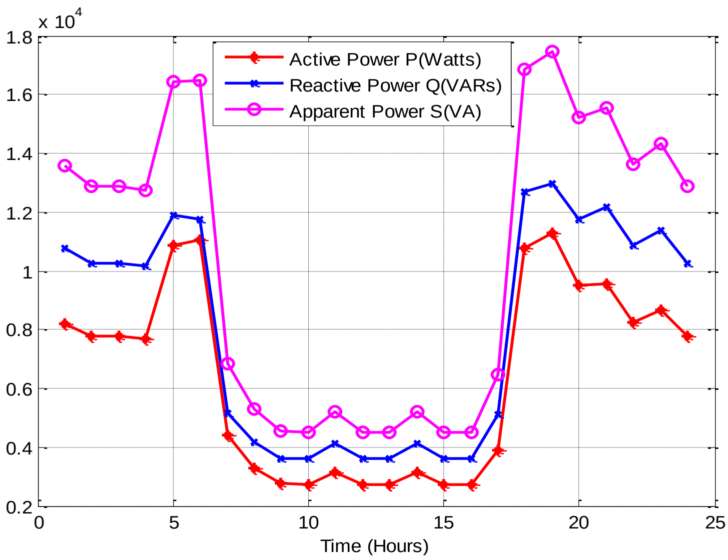

Figure 7. Load duration curve 3BHKV76

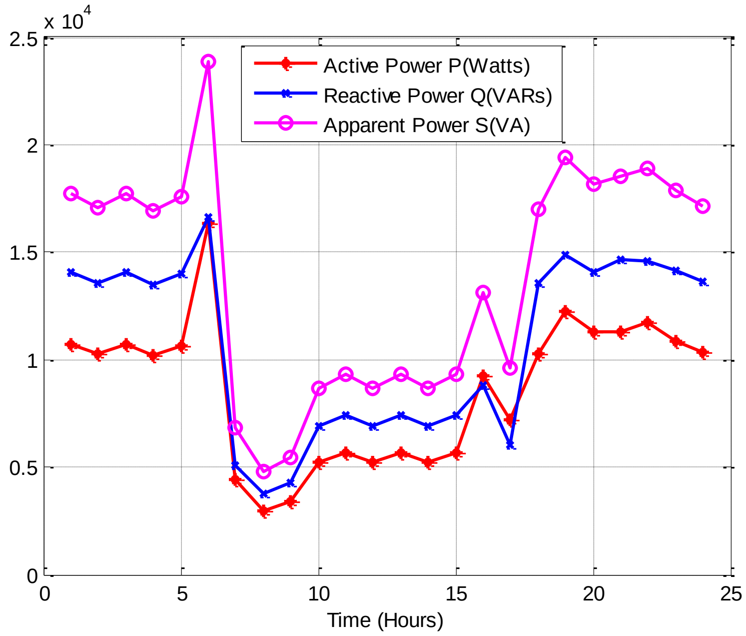

Figure 8. Load duration curve 4BHKV73

During data collection from different apartments and villas, it has observed the initial power factor (without connecting the switching capacitor) at point of common coupling (PCC) i.e. energy meter was in the range of 0.74 to 0.8. Therefore, an average of 0.77 power factor lagging has taken into account to determine the initial apparent power of the dwellings and has estimated 5269.76 kVA. To abide prescribed power factor limits of local utility, the switching capacitors installed for experiment are set to improve the power factor up to 90%.

The applicable residential tariffs in Oman are spread in different blocks according to the number of units consumed per month but for calculations, the most appropriate tariff is taken as USD 0.052 per kWh. It was observed from Table 4 that after installing the switching capacitors at different categories of apartments and villas, about 12.22% of apparent power capacity could be saved for the local utility. Further the average loss reductions of 70.88 kW per hour could be achieved at community microgrid network. The loss reduction increased when the power network was taken from mic rogrid to utility substation.

Table 4. Capacity savings

Category	Maximum Demand (Watts)	SAVINGS		Total Aprt. Nos	Total kVA Saving
		Q (VAr)	S(VA)		
2BHK48X3	5087	1360.83	885.90	144	85.05
3BHK24X6	8863	3062.18	1991.76	144	191.21
3BHKV76	11286	4882.63	3188.46	76	161.55
4BHKV73	16317.5	6503.59	4245.21	73	206.60
Total	**41.55 kW**	**15.81 kVAr**	**10.31 kVA**	**437**	**644.41**

5. CONCLUSION

The automatically switched capacitors were installed in all four categories of dwellings to improve power factor from 0.77 to 0.90 for a community microgrid. About 12.22% capacity savings can be achieved by implementing power saver units. Also, the average loss reduction was estimated as 70.88 kW per hour. According to applicable tariff, USD 3.68 can be saved per hour approximately. If this approach of loss minimization is integrated to the residential and other sectors in Oman, it will be beneficial to consumers as well to the local utilities. Therefore, it is recommended to integrate this technique to other sectors for capacity savings and loss minimization.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Sasidharan Sreedharan	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
Parmal Singh Solanki		✓				✓		✓	✓	✓	✓	✓	✓	✓
Magdy S. Abdelfatah	✓		✓	✓		✓		✓	✓		✓	✓	✓	✓
I Made Wartana	✓								✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [Sasidharan Sreedharan]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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