TECHNO-ECONOMICS OF UPS SYSTEM AS BACKUP POWER SOURCE DURING LOAD SHEDDING

Uzma Nawaz[1*], Muhammad Iftikhar Khan[1], Muhammad Naeem Arbab[1]

ABSTRACT

The energy crises in Pakistan of the last two decades has forced electricity consumers to use backup power sources based on portable generator sets and Un-interrupted Power Supply (UPS) devices. In order to maintain continuity of supply to basic appliances such as lights and ceiling fans, the majority of consumers use UPS with battery backup due to its less initial cost compared to portable generator sets. Following the increased use of battery based UPS as backup power source, several technical and economic issues due to their use have not been addressed. The main component of UPS system is the battery, which is costly and has to be replaced after its useful service life. Failure to do so, the cost of utility bills increases since batteries operate charge at low efficiency, and have undesirable impact on consumer loads. In this work a survey highlighting the technical and economic issues with UPS system is described that allowed obtaining a cost model based on useful service life of battery, which have also been investigated with the local brands of batteries. The results showed the battery useful life as a function of charging/discharging cycles. In particular analysis shows that the operating cost of the battery increases with the number of cycles the battery undergoes. The work will form a platform for conducting studies related to UPS, for setting standards, policy and the areas where improvement is needed.

KEY WORDS: *UPS, Batteries, Energy, Cycle, Cost*

INTRODUCTION

With the growing demand for electrical energy and failure to maintain balance between generation and demand, Pakistan has plunged into energy crises since last two decades (Khan & Ashraf, 2015). In an attempt to bridge this gap, the Government of Pakistan (GoP) inducted IPPs (Independent Power Producers), mostly thermal (Khan, 2014) (Ali & Baig, 2007). Non recovery due to circular debt (Haque, 2013) (Fin.Div., 2014-15) surging fuel price (World Bank, 2013), poor management (Malik,2012) (Saleem, 2015) and lack of coordination (Malik, 2007) has increased the cost of electricity(Lodhi, 2016) (World Bank, 2017). Recently the GoP encouraged the energy sector to develop renewable energy resources for electricity production (Kamran, 2018). However, due to its intermittent nature at selected sites and high initial cost, there has been little progress (Asghar, 2018). Pakistan is also blessed with enormous potential for hydropower, but because of political and socio-economic factors there has been slow progress towards development of mega hydroelectric projects (GoP, 2011). Thus with the gap between generation and demand progressively widening, there seems no immediate solution to combat the energy crises in near future (Arif, 2015). This has forced the utility companies to resort to hourly load shedding, as remedial measure adopted to maintain balance between generation and demand, which varies from 2 to 8 hours in urban areas and 8 to 14 hours, or even greater in rural areas. Load shedding follows different seasonal pattern, and varies time to time during day and night. In order to maintain continuity of power to basic home appliances such as ceiling fans and light bulbs during load shedding hours, consumers used portable power sources based on petrol, gas or Diesel generator sets. However, because of their high capital and operating cost, noise and environmental pollution these generator sets are uncommon. Thus majority of consumers use Uninterrupted Power Supply (UPS) with batteries as an alternative supply source during load shedding irrespective of its negative impact on home appliances (EC&M, 2017).

With UPS system becoming popular, millions of batteries have been sold since the beginning of the energy crises with no data available on their techno-economic issues related to their performance. In this paper a techno-economic study is conducted UPS system based on market and consumer survey. The most important component of the UPS system is the battery, which is

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costly, requires routine maintenance and needs replacement after its useful life. In this paper the performance characteristics of locally manufactured batteries are also presented based on experimental determination of their life expectancy. A mathematical cost and power capability model based on least-square approximation has been obtained for local brands of batteries commonly used with UPS.

SURVEY

For techno-economic study of UPS system, a market and consumer survey was conducted through a questionnaire by randomly selecting 600 electricity consumers with 400 living in the urban and 200 in rural areas of Peshawar District. The main components of the questionnaire included rating of UPS, and batteries used, their cost, routine maintenance, their replacement time, daily use, faults. The survey results are presented in pie-charts shown in Fig. 1 to 8.

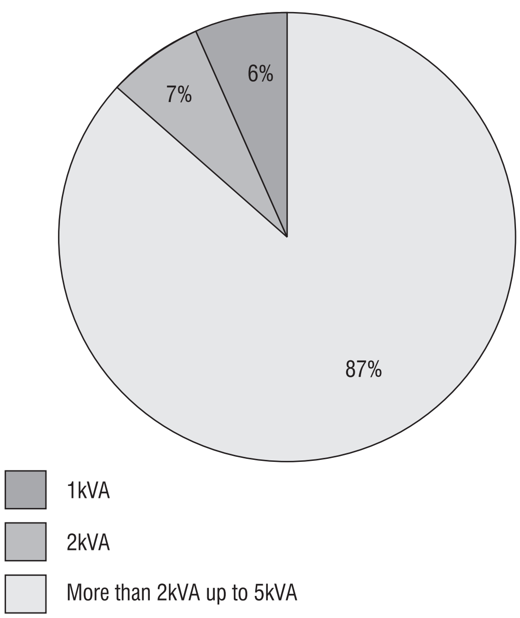

Fig. 1: Rating of UPS

The information collected through the survey was analysed statistically using SPSS v25 software. Market survey indicates that the cost of UPS and battery are approximately Rs. 15.27/VA and Rs. 115/Ah respectively. The results of consumers survey are summarized as: average consumer uses 1000VA with 12 volts, 120Ah local manufactured battery with electrical load comprising

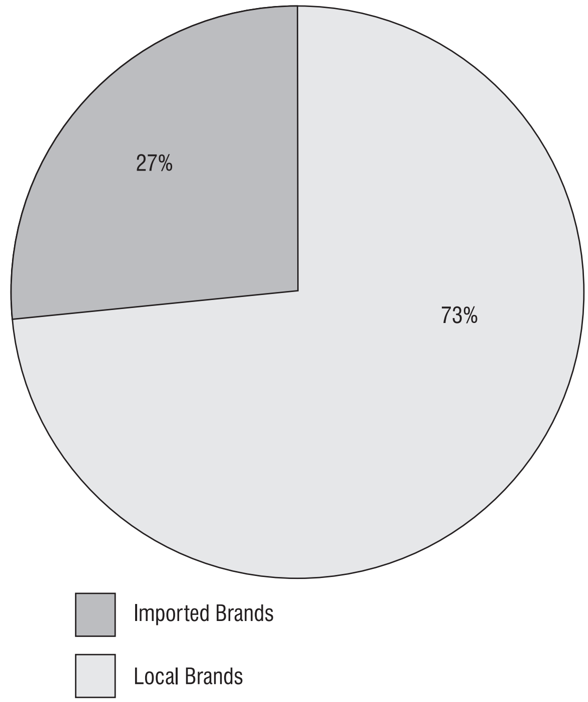

Fig. 2: Batteries used (local and imported)

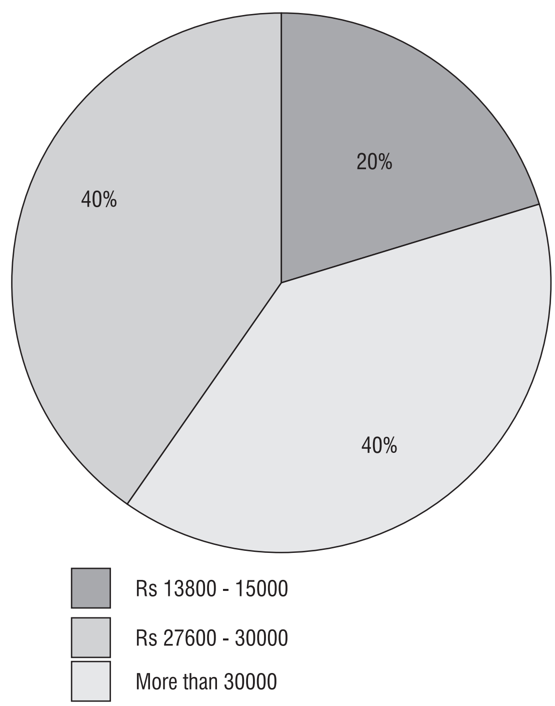

Fig. 3: Amount spent by consumers on batteries

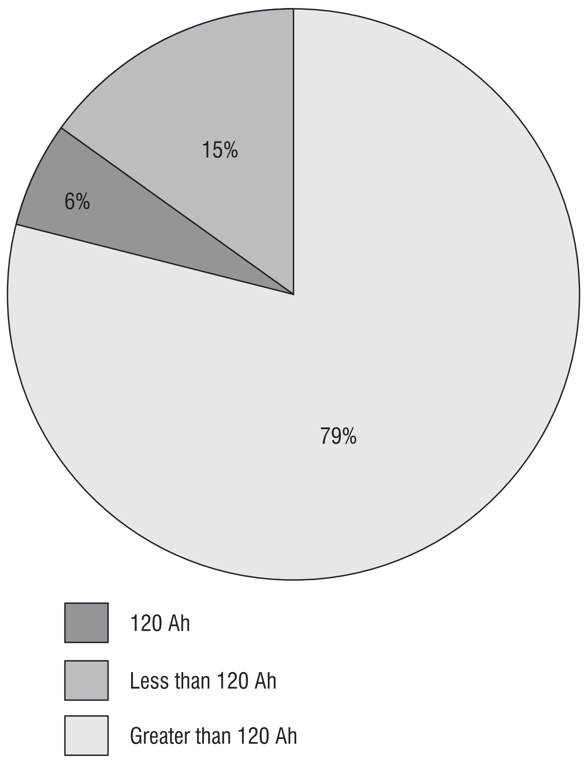

Fig. 4: battery rating in Ah used by consumers

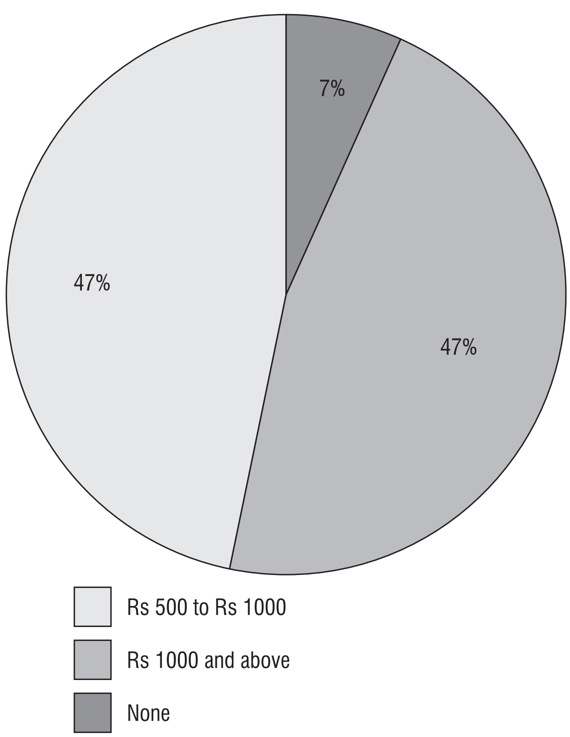

Fig. 5: Approximate amount spent per year on battery maintenance

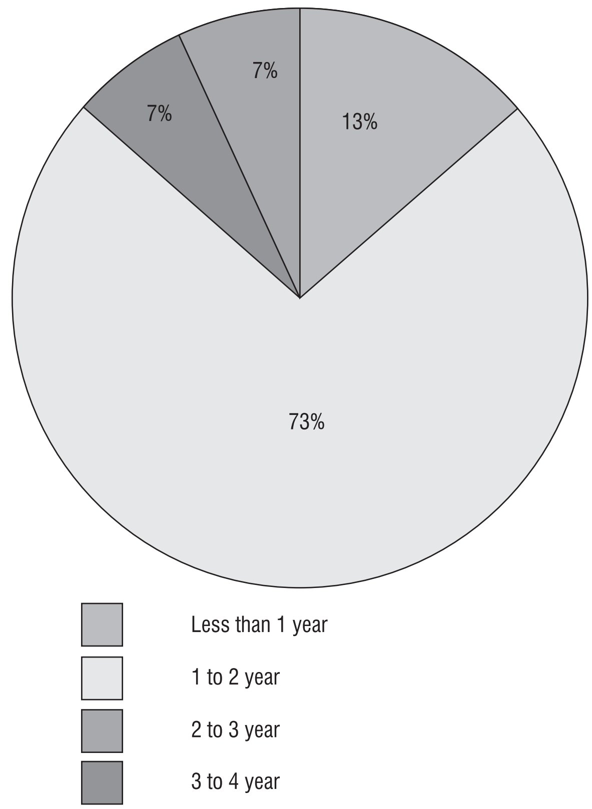

Fig. 6: Battery replacement time

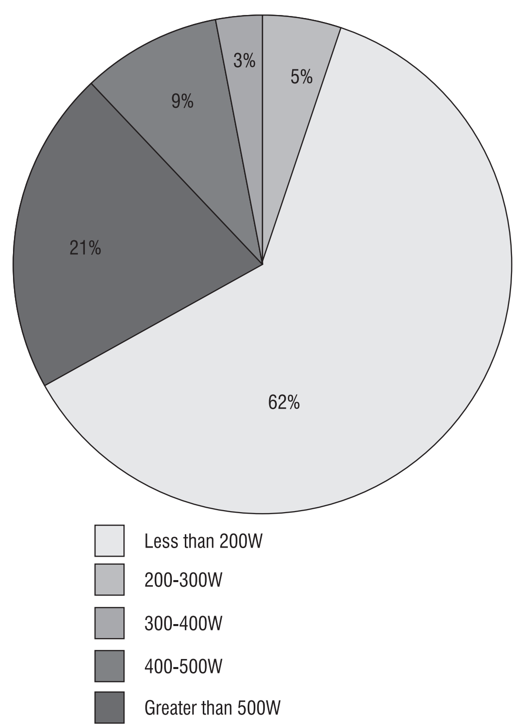

Fig. 7: Load with 1000VA UPS

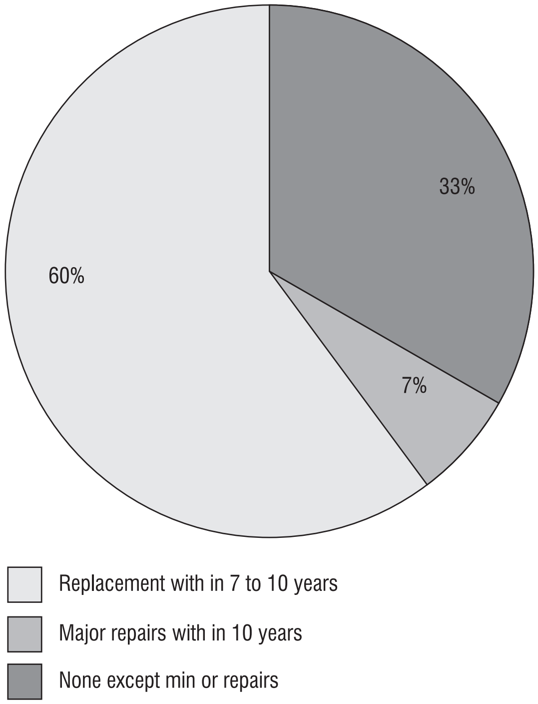

Fig. 8: UPS Faults and Replacement

of two ceiling fans and light bulbs, amounting to about 275 Watts, replaces battery in about 1.58 years and UPS in about 8.5 years. The average daily load shedding duration for urban and rural consumers is 5 and 12 hours respectively.

PERFORMANCE AND LIFE EXPECTANCY OF LOCALLY MANUFACTURED BATTERIES

For techno-economic analysis, it is essential to know the energy efficiency η_B of batteries used with UPS and their useful service life. The useful service life of the battery in the present work is defined in-terms of benefit drawn from battery to provide energy to basic load of 275 Watts for at-least an hour of load shedding duration. Five different local brands of new 12 volts, 120Ah batteries were tested for energy efficiency by the experimental set-up shown in Fig. 9. Referring to Fig. 9, DC energy meters were connected in both load and supply circuit of the battery under test to read respectively E_D (energy discharged by battery) and E_C (energy provided by charger during charging) converted from Ah to kWh. A switch S facilitates to connect the battery to the supply and load for charging and discharging respectively. The charger used was heavy duty, Schumacher Model SSC-1000A, 5kVA, with output voltage settings in the range of 9 to 110 volts and maximum current rating 300A, and efficiency >75%. The charger has in-built charge controller, voltmeter, ammeter, digital stop watch that derives signal from the tripping mechanism incorporated with the charger's State of Charge (SoC) measuring unit with pre-set alarm activation when desired depth of discharge is reached. The alarm setting of SoC measuring unit of the battery charger was pre-set to operate on 80% discharge at which the tripping mechanism activates the alarm with stop watch registering the time.

A reduction to 80% of the rated capacity is usually defined as the end of life for a lead-acid battery (Dinis *et al.,* 2014). Below 80%, the rate of battery deterioration accelerates, and is prone to failure resulting in a high discharge rate (Catherino *et al.* 2004). Thus when the battery 80% discharges, the alarm sounds followed by automatic tripping of the charging circuit. Once discharged the battery was fully charged from mains supply and the energy E_S taken from supply was noted from the utility energy meter connected between charger and

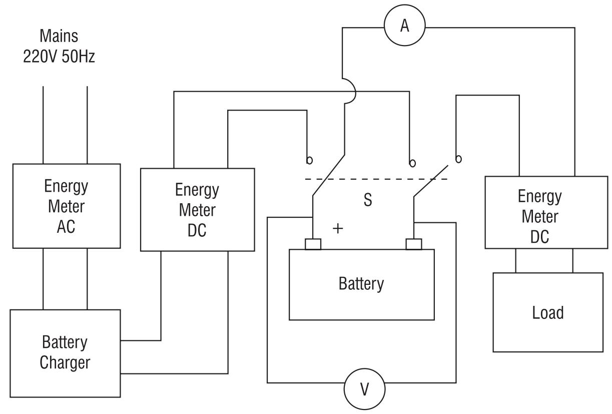

Fig. 9: Experimental set-up for finding the energy efficiency

mains supply. One discharge combined with charging in this paper is referred to as a cycle.

The first phase of experiment was with new batteries. Prior to starting the experiment, each battery was filled with standard electrolyte to the desired level. The battery was then inserted in the test circuit and initially charged to 99% (fully charged conditions) at 1C rate from utility mains supply. Once fully charged, the battery was switched to the load and its discharge was initiated. The load was a 1kW resistor adjusted to 0.15 Ohms to allow the battery to discharge at approximately 1C rate. The SoC of the battery was monitored throughout the discharge process, with test terminated when the SoC was 20%, indicating 80% discharge. The test was repeated three times for each new battery and the average value of energy required to charge and energy discharged through the load were calculated. Knowing the E_C and E_D, the energy efficiency of the battery η_B was calculated using:

$$\eta_B = \frac{E_D}{E_C} \times 100 \qquad (1)$$

For techno-economics, the cost of battery in-terms of its useful service life had to be determined, but experimental investigation of battery performance and life estimation is a long-term study (Abed *et al*., 2018). However, in order to compile results in relatively short time, batteries already in service for different span of time were selected through intense scrutiny among consumers who were the subject of survey. The selection criterion was based on acquiring (on request) non-recycled 12 volts, 120 Ah local brands batteries that were maintained according to manufacturer's instructions and had been in service for at least a month. Thus 15 consumers (rural and urban) were carefully selected, who donated their batteries, with necessary data; including the daily load shedding hours (*t*), maintenance record and the number of days the battery had been in service obtained. From the available data the numbers of cycles *N* the battery has undergone were calculated for each battery. The batteries were then labelled in chronological order according to the number of cycles the battery had undergone during service and is given in Table 1.

The experimental procedure for life expectancy was same as outlined above with set-up shown in Fig. 9, except that the load resistance was adjusted to 12 Ohms, approximately amounted to 275 Watts. All the batteries listed in Table 1 were tested by the same procedure.

Table 1: Data of batteries acquired from consumers (used batteries)

Battery Label	Service days	Daily load shedding hours (t)	N
1	34	4	136
2	73	3	219
3	90	5	450
4	122	6	732
5	192	5	960
6	252	5	1260
7	359	5	1795
8	380	5	1900
9	177	12	2124
10	368	6	2208
11	765	3	2295
12	392	6	2352
13	402	6	2412
14	643	4	2572
15	543	5	2715

RESULTS OF LIFE EXPECTANCY TEST

The results of tests with new batteries are given in Table 2.

Table 2: Test results of new batteries

Battery	EC kWh	ED kWh	ES kWh	ηB (%)
1	1.48	1.08	1.88	73.01
2	1.47	1.08	1.88	73.21
3	1.47	1.08	1.88	73.26
4	1.47	1.08	1.88	73.18
5	1.47	1.08	1.88	73.27

The values of energy efficiency as found experimentally that are given in Table 2 are consistent with those obtained by others (Chih *et al*., 2014) (Jung *et al*., 2015). The results also show that there is no significant difference in battery energy efficiency among local manufactured brands. The results of test with used batteries are given in Table 3 and displayed graphically in Fig. 10 to 12.

It can be seen from graph of Fig. 10 and 11 that both time to discharge to 80% and energy efficiency

Table 3: Test results of used batteries

N	T (hrs)	ED kWh	EC kWh	ES kWh	ηB(%)
136	2.51	1.02	1.45	1.90	70.34
219	2.18	1.02	1.46	1.90	69.88
450	2.07	1.02	1.46	1.90	69.88
732	1.49	1.02	1.47	1.91	69.63
960	1.40	1.01	1.47	1.92	68.70
1260	1.36	1.01	1.48	1.93	68.26
1795	1.13	1.01	1.50	1.96	67.33
1900	1.09	1.01	1.51	1.98	66.88
2124	1.01	1.00	1.58	2.09	63.30
2208	0.94	0.97	1.61	2.12	60.24
2295	0.78	0.96	1.76	2.29	54.54
2352	0.69	0.93	1.81	2.36	51.38
2412	0.67	0.90	1.83	2.39	49.18
2572	0.59	0.88	2.02	2.57	43.56
2715	0.57	0.84	2.53	3.35	33.20

decline with the number of cycles the batteries undergoes in service. Battery efficiency deteriorates with time of use and reaches about 60% at the end of its useful life. However, according to others (Chih *et al.*, 2014) (Jung *et al.*, 2015) ((Minami *et al.*, 2003) (Bungeler *et al.*, 2018) battery efficiency deteriorates to 50% with time; following continuous or intermittent charging and discharging. From the graph of Fig. 10, it is evident that the time to discharge decreases rapidly beyond about 2208 cycles. From Table 3 it can be seen that the time of utilization of battery energy almost one hour for 2124 cycles but is a little less than an hour for 2208 cycles. Roughly 2200 cycles can be considered for estimating the useful service life of locally manufactured batteries as most manufacturers provide warranties based on the number of discharge cycles.

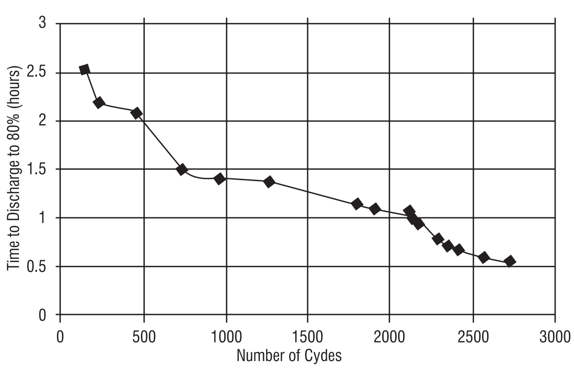

Fig. 10: Time to discharge to 80% vs number of cycles

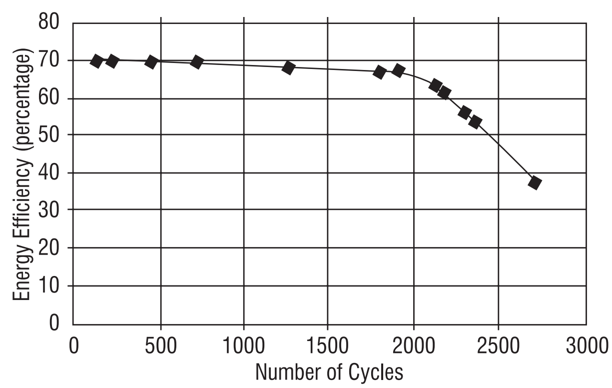

Fig. 11: Energy efficiency vs number of cycles

Thus the useful life of the battery in years (n) for daily load shedding hours (t) is:

$$n = \frac{2200}{365t} = \frac{6.027}{t} \qquad (2)$$

However, decrease in electrical load will increase the discharge time and therefore the time of utilization of battery energy. The benefit drawn from the UPS system will reduce since load less than 275 Watts will be used for one hour when the battery cycles increases beyond about 2200. From the data given in Table 3, using the least-square approximation, the electrical load used with UPS system can be estimated for the number of cycles the battery has undergone. For up to 2200 cycles or useful life of battery, the power capacity P_B of the battery is:

$$P_B = 733 - 0.34N + 6\times10^{-5}N^2 \tag{3}$$

For cycles greater than 2200:

$$P_B = 699 - 0.3N + 3.1\times10^{-5}N^2 \tag{4}$$

From the graph of Fig. 12 it can be seen that the amount of electrical energy required from utility supply to charge the battery increases with the number of cycles.

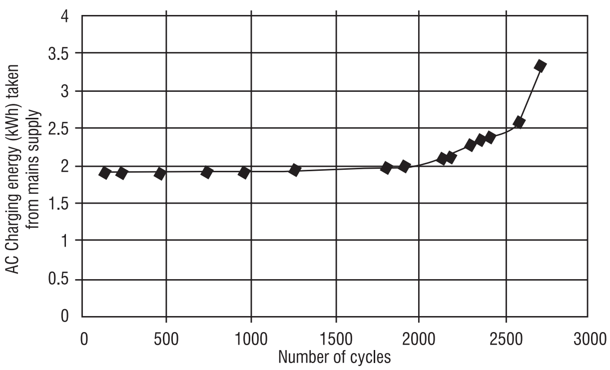

Fig. 12: AC energy for charging the battery versus number of cycles

A cost model developed from the graph of Fig. 12 through curve-fitting based on least-square approximation is:

$$E_S = 1.833 - 8.78\times10^{-5}N + 1.46\times10^{-7}N^2 \tag{5}$$

The cost of charging the battery from utility supply following load shedding will therefore increase as the battery gets older. Thus over the useful life of battery the expected amount of electrical energy required to charge the battery from utility supply will exceed 2 kWh.

TECHNO-ECONOMICS

Techno-economic analysis is based on the data collected from market and consumer survey conducted. The objective is to arrive at the total annual cost C_{TOT} comprising of annual cost of UPS C_u, annual cost of batteries C_b and the operational cost C_{OP}. Thus:

$$C_{TOT} = C_u + C_b + C_{OP} \tag{6}$$

On the basis of expected useful life of 8.5 years, the capital cost of UPS C_{UPS} is:

$$C_u = \frac{C_{UPS}}{8.5} \tag{7}$$

Or C_u = Rs. 1796/year

Annual cost of battery C_b is based on its capital cost C_B, depreciated over its useful life (in years) given by:

$$C_b = \frac{C_B}{n} \tag{8}$$

Based on 1.2 years for urban and 0.5 years for rural consumers respectively from Eq. 2, and Eq. 8, the annual cost of 120Ah battery is Rs. 11897 and Rs. 28750 for urban and rural consumers respectively. Thus the fixed cost per year C_F depreciated over the useful life of UPS system (UPS and battery) for urban and rural consumers respectively are: Rs. 13693 and Rs. 30546. The prices of batteries and UPS are also subject to inflation. Taking inflation into account and using the compound interest, the fixed cost of UPS system after m years with inflation annual inflation rate r, will be:

$$C_{Fm} = C_F[1 + (1 + r)^m] \tag{9}$$

The operating cost C_{OP} is based on the kWh consumed E_S from the mains supply during charging, which varies over its life time with number of cycles. The operating cost is determined from the cost of electricity (*COE*) based on the domestic tariff. Thus:

$$C_{OP} = COE(E_S) \tag{10}$$

Based on domestic tariff of Peshawar Electric Supply Company (PESCO), the COE presently is Rs. 13.85/kWh. Thus for use of 12 volts, 120Ah battery with UPS, the operating cost increases from Rs. 25/hour with new battery (N=1) to Rs. 32/hour for batteries that have almost completed its useful service life (N = 2200). For older batteries the cost calculated from Eq. 5, for example for a battery with replacement time of 1.58 years would roughly undergo 2883 cycles and operating cost will be in excess of Rs. 40/hour of use and discharge in less than hour. However, for 2883 cycles, power capacity of battery is less than about 100 Watts as calculated using Eq. 4, insufficient for even a single ceiling fan. Thus the benefits that can be drawn are far less than the usual average, and together with high operating cost can produce significant impact.

CONCLUSIONS

The techno-economic study was performed on data collected in the survey. UPS system is favourite option as backup source during load shedding, but majority of the consumers are unaware of the technical and economic issues that include the battery life-time and the amount they are spending on utility bills on charging their batteries from mains supply. The battery performance usually deteriorates in service and the use of battery beyond its useful life will be uneconomical and the technical benefits are less. A cost model has been developed for locally manufactured batteries that allow estimating the operating cost over the number of cycles. In addition the load model developed allows the consumers to estimate the benefits that can be drawn from the UPS system, which can also be used as a linear prediction model when determining the cost-benefit of battery replacement at the end of its useful life.

Most of the UPS are locally manufactured and incorporate sub-standard components. However, due to their high capital and operating cost, noise and environmental issues with portable generator sets, UPS system is still the most common and relatively low cost option for use during load shedding.

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