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Techno-economics and environmental analysis of energy storage for a student residence under a South African time-of-use tariff rate

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ABSTRACT

Time-of-Use has been introduced in South Africa as part of demand side management measures. Battery energy storage (BES) can take advantage of energy price arbitrage under favourable pricing regimes. However, the challenge is to what extent will the introduced policy favour the installation of BES at residential accommodations? The tools to assess suitability of installing BES exist but they come at a cost. In this study, we improved upon existing methodology and implemented it in Microsoft Excel to assess techno-economic viability and environmental benefits of using BES. The approach showed that none of the three BES technologies investigated was economically viable at the prevailing average rate of 0.1442 $/kWh for peak electricity. The Monte Carlo simulation implemented suggests that the minimum mean price of peak needed for the BES system to break even range between 0.2560 – 0.2919 $/kWh. At 50% discount in storage medium cost and 100% increase in the price of peak, the BES will only break even when the average price of peak is 0.2043 $/kWh at maximum cycling cost that range between 0.1077 – 0.1560 $/kWh. The study concluded that reduction in the cost of storage medium has more impact on economic viability than increasing only peak price of electricity.

1. Introduction

Emerging economies will account for about 90% of the global net energy demand growth by 2035 [1]. Electricity demand will be higher among other forms of energy in the emerging economies [1]. This projected growth has increased the interest in improved energy efficiency to limit the risk and environmental impact of the sources of energy which are mostly from fossil fuel [2,3]. South Africa's economy, identified as an emerging economy, is energy intensive and in recent years, economic growth coupled with increased access to electricity by previously unserved communities, has led to an increased demand for electricity, that at some point in 2008, exceeded generation capacity [2,4]. This situation forced Eskom, the state-owned utility which accounts for more than 95% of electricity generated and distributed nationwide [5], into controlled load shedding with an estimated economic impact of about US$268 million [5]. To avoid a repeat of that magnitude of load shedding, Eskom embarked on two major mitigating strategies. The first of these strategies was to build new baseload power plants, as well as re-commission and upgrade old power stations where feasible, to support peaking power plant requirements. The second strategy focused on implementing consumer demand reduction through integrated demand management (IDM) [5–7]. The target of the first strategy was to add 17,000 MW to electricity generating capacity by the end of 2019 [6]. Efforts under that strategy led to 3655 MW added to the grid in 2013 and another 9564 MW is expected by the end of 2017 from two coal power plants [7]. Also, 1600 MW of renewable sourced energy was added to the grid in 2014 as part of the first strategy [8]. The second strategy, IDM, aimed to increase energy efficiency and was made up of a series of demand side management (DSM) programmes namely; energy efficient DSM; demand response and energy conservation [5]. With the implementation of the IDM, 19 GWh annualised energy savings was achieved in 2013/14 [7]. The successes achieved on the two strategies, are under threat due to Eskom's aging fleet. The utility reported that two-third of its power stations are beyond the mid-point of their expected life span [7]. This is indicative that continued expansion and upgrading of the country's power generation and grid infrastructure is required, to ensure that generation keeps pace with demand in the medium to

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Nomenclature

Acronyms

LD and HD	Refers to low demand (summer) and high demand (winter)
$PrEl_{peak}$	Price of electricity at peak TOU [$/kWh]
$PrEl_{stand}$	Price of electricity at standard TOU [$/kWh]
$PrEl_{offpeak}$	Price of electricity at offpeak TOU [$/kWh]
E_{peak}	Summation of AC energy consumed during peak [kWh]
E_{stand}	Summation of AC energy consumed during standard period [kWh]
$E_{offpeak}$	Summation of AC energy consumed during offpeak period [kWh]
$I_{batt}(t)$	The current in/out of the battery [A]
I_{max}	Maximum current to charge the battery without damage [A]
SOC	State of charge of the battery
Cap_{batt}	The battery capacity [kWh]
P_{max}	Maximum absorbable power from the AC grid [kW]
$P_{load}(t)$	Average demand over hour t [kW]
$\eta_{\frac{AC}{DC}}$	AC-DC converter, the rectifier, efficiency [%]
$\eta_{\frac{DC}{AC}}$	DC-AC converter, the inverter, efficiency [%}
$\eta_{batt_{ch}}$	Battery charging efficiency [%]
$\eta_{batt_{disch}}$	Battery discharging efficiency [%]
P_{bi_dir}	The rated power of the bi-directional converter [kW]
V_{DC}	The DC bus voltage [V]
$P_{from_{batt}}(t)$	The load demand met by the battery during peak hours [kW]
$P_{peak_{dir}}(t)$	The load demand not met by battery during peak hours [kW]
δ	Self-discharge rate
$life_k$	Life of component k [years]
$life_{pro}$	Life of project [years]
DoD	Depth of discharge
R_k	Number of replacement of component k within project life [#]
NPC_k	Net present cost of component k [$]
$N_{cycles\ @\ \%DoD}$	Number cycles at depth of discharge [#]
$E_{from-batt}$	Load met by the battery [kWh/day]
$cost_k$	Cost of component k [$]
E_{peak_dir}	Daily load during peak hours not met by the battery purchased from the grid [kWh/day]
g_k	Yearly inflation rate for cost of component k [%]
i	Annual interest rate [%]
$NPC_{O\&M}$	Net present cost for operation and maintenance [$/kW-yr]
$cost_{O\&M}$	Unit operation and maintenance cost [$/kW]
$g_{O\&M}$	Yearly operation and maintenance cost inflation rate [%]
g_{PrEl}	Yearly inflation rate for price of electricity [%]
$NPC_{wout_{ES}}$	Net present cost for system without battery energy storage [$]
$NPC_{with_{ES}}$	Net present cost for system with battery energy storage [$]
$NPV_{savings}$	Net present saving [$]
$LCOE$	Levelized cost of electricity [$/kWh]
IRR	Internal rate of return [%]
$cost_{fixed\ \ year}$	Annual fixed service and demand charges [$/yr]
d	Day of the year [1–365]
t	Hour of the year [0–8759]
h	Hour of the day [0–23]
Δt	Time step of simulation [1 h used]
NPC_{all_comp}	The sum of NPC of all k components and the O&M cost [$]
$NPC_{E\_from\_batt}$	The NPC of energy to charge the battery [$]
∂_h	Hourly noise factor
∂_d	Daily noise factor
$El_{quality}$	Life time benefit for electricity quality [$]
$Grid_{cap\_ut}$	Life time benefit for grid capacity utilization [$]
$C_{Savings}$	Coal savings [kg]
C_{cons_peak}	Coal consumption during peak [kg]
$C_{cons\_offpeak}$	Coal consumption during offpeak [kg]
$CO_{2,\ Avoided}$	CO_2 avoided [kg]
$CO_{Avoided}$	CO avoided [kg]
$SO_{2,\ Avoided}$	SO_2 avoided [kg]
$NO_{x,\ Avoided}$	NO_x avoided [kg]
S_{ar}	Rate of sulphur removal [%]
t_s	Percentage of SO_2 emission out of sulphur in coal [%]
η_s	Desulphurisation rate [%]
N_N	Mass fraction of nitrogen in coal [%]
η_n	Efficiency of nitrogen to be converted into NOx [%]
γ	Percentage of NOx from the fuel out of the total amounts of NO_X emissions [%]
η_N	Nitrogen removal efficiency [%]

long term. However, South Africa's international and domestic commitments to climate change mitigation means that a significant part of any new generation infrastructure, needs to be based on sources “cleaner” than coal. However, cleaner, renewable sources like wind and solar that forms the major part of the renewable energy independent power producer procurement (REIPPP) are intermittent and thus present challenges to grid stability and grid management, especially at high penetration levels. It is widely recognised that energy storage is one of the major ways to address this challenge. But energy storage technologies are still relatively expensive, requiring policy and regulatory interventions that improve the commercial viability of their implementation. The time-of-use (ToU) tariff system is one such regulatory tool. ToU pricing divides a day into two or three segments with different prices that remain fixed day-to-day over a season.

The ToU tariff system has been introduced by Eskom in some part of the country. It is an element within the IDM, and has been introduced to reduce peak demand aside a yearly increase in tariff. A ToU allows for flexibility of demand deferment with potential to reduce customer electricity bill. It can reduce whole market prices of electricity, avoid or defer capacity investment, give utility an opportunity to operate with more level demand curve, increase the integration of distributed energy sources, and decrease environmental pollution by avoiding the need for operating a power plant at peak period [9,10]. Deployment of energy storage (ES) can be advantageous due to the different pricing regimes for end customers. ES system assists in storing energy during low electric price regimes and discharge the stored energy when the applicable charge is at peak ToU, usually with a high tariff. This DSM strategy helps to reschedule energy consumption over a period of time and