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# Environmental feasibility of incorporation of electric taxis in South Africa

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*Ranjay Singh*[1], *Abhishek Kumar*[2] ✉, *Arvind R. Singh*[1], *Raj Naidoo*[1], *R. C. Bansal*[3], *Praveen Kumar*[4]

[1]*Department of Electrical, Electronics and Computer Engineering, University of Pretoria, South Africa*
[2]*College of Electrical Engineering, Zhejiang University, People's Republic of China*
[3]*Electrical and Computer Engineering Department, University of Sharjah, United Arab Emirates*
[4]*Department of Electronics and Electrical Engineering, IIT Guwahati, India*
✉ *E-mail: abhi@zju.edu.cn*

**Abstract:** Public transport is very influential industry affecting our society due to its significant environmental and social impact. Policy makers have seen electric vehicle as a tool to reduce greenhouse gas emissions. Cleanliness of power from the electricity grid plays a vital role in environmental impact in the transition to electric vehicle. In countries like China, USA, India etc., majority of electricity generation is still dominated by fossil fuel fired generators. Thus, in some cases, the environmental impact of electric vehicle may be more adverse in comparison to conventional internal combustion engine vehicles (ICEV). This paper tries to study the environmental effect of incorporation of 100 Electric Vehicle taxies in Johannesburg (JNB), South Africa. Firstly, the current electricity generation scenario and vehicles standards of SA with its carbon emission is discussed. Secondly, it is shown that with the current generation mix the adoption of EV is not sustainable. Finally, penetration of Renewable Energy (RE) system at charging stations is proposed with Renewable Energy Fraction (REF) of 40% and 58% to make carbon mission from EV equivalent to Euro III and Euro V standards of petrol ICEV. The optimised size of RE system is found using the Electric System Cascade Analysis.

## 1 Introduction

Increasing worldwide attention towards environmental issues has led many governments and organisations to minimise the negative environmental influence of power generation and transportation system [1]. High dependency of public transportation on fossil fuels is considered one of the most significant governmental concern [2]. Electric Vehicle (EV) provides a promising solution to reduce the carbon emission of the transportation sector. The main advantage of EV is that it can use electricity produced from all kind of energy sources thereby reducing dependency on the volatile fossil fuel market [3]. There is barely any emission in the end use of EV which helps to reduce the carbon emission. The USA government has adopted over 80,000 alternate fuel vehicles by 2015 and aim to manufacture and sell over 920,000 EVs and 600,000 alternate fuel vehicles by 2020, The South Korean government aims to adopt over 2.2 million eco-friendly vehicles by 2020 under the 'Green Car Development Roadmap' [4], United Kingdom aims to induct 1.7 million EVs by 2020 under its committee on climate change [5], China aims to manufacture and adopt 5 million EVs by 2020 based on its report of energy saving and energy automobile industry planning (2012–2020) [6] and India has set an ambitious goal to have 30% of all the vehicles to be electric by 2030.

Although EVs are generally considered clean, their environmental implications depend on the cleanliness of the electricity grid which is used to charge them. National research council in USA released a report which shows that the aggregate life cycle of EVs depends highly on grid and for the cases considered in the report, the emission of the EV is higher than those of petrol vehicle in the USA as majority of electricity produced in the USA is by coal and natural gas powered power generation [7]. Huo *et al.* [8], studied the environmental impact of EVs in China which showed that the EVs charged from the utility grid could increase $SO_x$ emission by three to ten times and $NO_x$ emission were found comparable to petrol vehicles. In addition to the utility cleanliness, increase in the peak load due to charging EVs on the national/local grid system needs to be evaluated [9]. For example, average peak electricity load of a household is 2 kW, which may increase to 6.6 kW due to the introduction of complex EV charging circuit [10]. In some cases high speed EV charger as in Tesla Model S may require 20 kW maximum peak load.

Therefore, the prime aim of this paper is to initially study the energy scenario of South Africa (SA) and find the feasibility of EV adoption with cleanliness of the utility grid under consideration. It is found that renewable penetration is required for EV adoption, the optimised size of the RE system thus required was found using ESCA optimisation technique [11]. The organisation of the paper is as follows: Section 2 explains the energy scenario and vehicle standard of SA for 2017 with projections for 2030, Section 3 puts forward the EV taxi specification and compares its carbon emissions with current vehicle standard in SA, Section 4 discusses the case study of EV taxi incorporation with the proposed solution followed by Section 5 which concludes the findings of the proposed solution for EV incorporation.

## 2 Energy scenario of South Africa

The current power installed capacity of South Africa (SA) is 46.41 GW which is estimated to increase to 81.9 GW by 2030 as forecasted by the Integrated Resource Plan (IRP) 2016 [12]. A summary of the current and future generation is presented in Table 1 [12, 13].

It is observed from Table 1 that, 91.25% (200,893 GWh) of the generation is contributed by coal powered fired station. The current renewable generation contribution is very small (0.9%). According to IRP projections, an additional 35.5 GW of power would be required in SA by 2030. Increment of renewable generation penetration will be 18.8 GW which contributes to 23% of the total generation mix of SA by 2030 [12]. In the current integrated report of ESKOM, the load area considered are distributors, commercial, agricultural, residential, mining, rail and industrial as shown in Fig. 1 [13], but electrical vehicle consumption is not catered in the above mentioned categories.

The current energy mix of SA is dominated by coal fired power stations therefore the electricity generated is not clean and has emission details as shown in Table 2 [12, 13].

**Table 1** Electricity generation mix of SA in 2017 and 2030

| Fuel Type | Installed capacity 2017 (GW) | Electricity output in 2017 (GWh) | Projected generation in 2030 (GW) |
|---|---|---|---|
| coal | 38.55 | 200,893 | 41.10 |
| nuclear | 1.94 | 15,026 | 11.40 |
| gas/liquid fuel | 2.43 | 29 | 2.90 |
| pumped Storage | 2.73 | 3,294 | 2.90 |
| hydro | 0.66 | 579 | 4.80 |
| renewables | 0.10 | 345 | 18.80 |
| total | 46.41 | 220,166 | 81.90 |

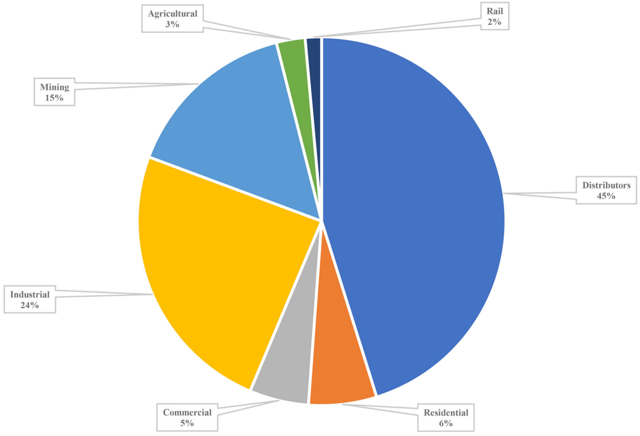

**Fig. 1** *Electrical consumption in various sectors in SA for 2017*

**Table 2** Carbon emission of the utility grid in SA for 2017 and projections for 2030

| Emission type | Emissions by weight | Emission in 2017 (g/kWh) | Emission in 2030 (g/kWh) |
|---|---|---|---|
| $CO_2$ | 211.11 Mt | 990 | 630 |
| $NO_x$ | 887.78 kt | 4.13 | 2.22 |
| $SO_x$ | 1766 kt | 8.25 | 4.95 |
| PM | 65.13 kt | 0.3 | 0.19 |
| $CO_2$ eq. | — | 2220 | 1291 |

*biomass generation and co-generation emissions were neglected.

**Table 3** Carbon emissions of vehicles in 2017 (Euro III) and 2030 (Euro V assumed)

| Type | Emission (g/km) | | | | | |
|---|---|---|---|---|---|---|
| | Petrol ICEV | | Diesel ICEV | | Petrol hybrid | |
| | 2017 | 2030 | 2017 | 2030 | 2017 | 2030 |
| $CO_2$ | 192 | 147 | 161 | 123 | 137 | 104 |
| $NO_x$ | 0.15 | 0.06 | 0.50 | 0.08 | 0.15 | 0.06 |
| $SO_x$ | 0.0520 | 0.0008 | 0.0430 | 0.007 | 0.0380 | 0.006 |
| PM | 0.0005 | — | 0.0500 | 0.0025 | — | — |
| $CO_2$ eq. | 237 | 165 | 310 | 147 | 182 | 122 |

The emission level shown in Table 2 is very high as compared to the USA, Australia and other European countries. Findings of von Blottnitz [14] show that high emission of SA power industries is due to large emission of sulphur oxides ($SO_x$), nitrous oxides ($NO_x$) and particulate matter (PM) as compared to 15 European countries considered in his study. Also, concluded in his study is high specific emission from coal powered plants in SA performing at worst level due to consumption of poor quality of coal and low efficiency of power generating stations. No major step/plan are presented in Eskom integrated report 2017, IRP 2010 and IRP 2016 to improve the efficiency and control the pollution from the coal fired power station. New technologies, like combustive $CO_2$ capture, wet phase transition agglomerator etc. exists to aid this process which is currently adopted worldwide [15–17]. Adoption of such technologies in the generation mix and load forecasting inclusive of electric vehicles should be incorporated in the future IRP.

### *2.1 Fuel and vehicle standards*

SA has no crude oil reserve and 60% of its crude oil is imported from the middle-East and other African countries [18]. In order to make petrol and diesel prices competitive significant amount of liquid fuel made from natural gas and coal is used in SA. Sasol produces refined petroleum from coal and PetroSA from gas, together they contribute 37% of total petroleum product in SA [19]. The current vehicles in SA follow the out-dated Euro III specification as reflected in SANS 10047:2009 report [20]. It is presumed that Euro V emission standard will comply in SA by 2030. The emission limits for internal combustion engine vehicle (ICEV) in 2010 and projected in 2030 are shown in Table 3 [21, 22].

According to the National Association of Automobile Manufacturer South Africa (NAAMSA) the fuel consumption of 1.6 L–1.8 L diesel ICEV light passenger car is 5.2 L/100 km and for petrol ICEV light passenger car is 7 L/100 km. The only hybrid

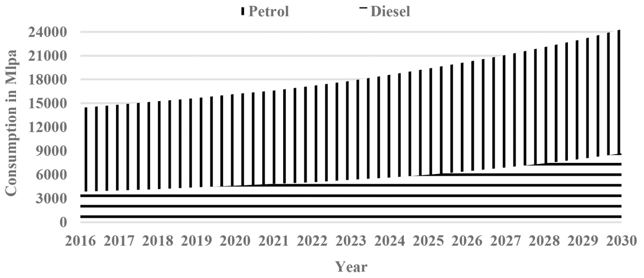

**Fig. 2** *Fuel consumption of automobiles in SA and there projection till 2030*

**Table 4** Vehicle composition of SA in 2017 and projections for 2020

| Broad Category | | 2017 | | 2030 | |
|---|---|---|---|---|---|
| | | Petrol | Diesel | Petrol | Diesel |
| PC | Car parc | 90% | 10% | 78% | 22% |
| | New sales | 85% | 15% | 75% | 25% |
| LCV | Car parc | 56% | 44% | 52% | 48% |
| | New sales | 60% | 40% | 50% | 50% |
| HCV | Car parc | 5% | 95% | 1% | 99% |
| | New sales | NA | NA | 0% | 100% |

PC-Passenger cars, LCV-Light commercial vehicle, HCV-Heavy commercial vehicle.
Parc- total no. of vehicles considered collectively.

**Table 5** Electric vehicle specifications and performance parameters

| **Dimensions** | **Values** |
|---|---|
| wheelbase | 2700 mm |
| length | 4750 mm |
| width | 1810 mm |
| height | 1460 mm |
| curb weight | 1565 kg |
| front wheel width | 205 mm |
| rear wheel width | 205 mm |
| maximum capacity | 5 |
| body style | 4 door sedan |
| **Performance parameters** | **Values** |
| electric motor | 95 Hp synchronous |
| acceleration (0–100 km) | 11.5 second |
| battery (Li-ion) | 22 kWh |
| maximum range | 135 km |
| charging plug | 3.5 kW on-board charger |

**Table 6** Carbon emission comparison for EV using current grid and Euro III ICEV taxi running 215 km

| Emission type | Carbon emission in 2017 (grams) | |
|---|---|---|
| | Grid | Petrol ICEV |
| $CO_2$ | 37,620 | 41,280 |
| $NO_x$ | 156.94 | 32.25 |
| $SO_x$ | 313.5 | 1.976 |
| PM | 11.4 | 0.1075 |
| $CO_2$ eq. | 84,360 | 50,955 |

passenger vehicle available in SA is Toyota Prius which has fuel consumption of 4.1 L/100 km [23]. The first native SA electrical vehicle ‘Joule’ was expected to launch in 2013 but as per current reports it has been decommissioned and the company Optimal Energy which was making Joule is now working on electric buses for SA automobile market. The increase in fuel consumption demands of SA as projected by NAAMSA in million litres per annum as shown in Fig. 2.

The composition of petrol and diesel vehicle in 2017 and 2030 as projected by NAAMSA is shown in Table 4. In its analysis the forecasting is based on the following formulation

$$\begin{aligned} \text{Futurecarparc} = \text{Existingcarparc} + \text{Newvehiclesale} \\ - \text{Attrition} \end{aligned}$$

## 3 Electric taxi incorporation

The prime aim of the paper is to show the feasibility/sustainability of incorporation of EVs with the current generation mix of SA. For this a case study of implementing 100 electric taxis in the city of Johannesburg is presented.

### *3.1 Electric taxi specification*

Presently the only electric vehicle (EV) available in SA is Toyota Prius as stated in section 2.1. Due to the higher price of Prius, for this case study the electric power taxi manufactured by Renault Samsung, a car manufacturer in South Korea is considered. The basis of selection of EV is the study conducted by local government of Daejeon for its implementation of electric power *t*-axis [24]. The vehicle specification is shown in Table 5 [24].

### *3.2 Impact of incorporation of ET to current grid*

Policymakers consider adoption of EV as a tool to reduce greenhouse emissions. But this policy is sustainable as long as the utility supplying the electrical energy to electric vehicle is clean. Since majority of the electricity generated in SA is from coal fired power station, EV incorporation will have an adverse effect on the climate in contrast to being fruitful. This is depicted by the analysis discussed in the following sections.

According to the report published by business tech SA, on an average a taxi in Johannesburg runs for 6500 km/month which equates to nearly 215 km/day. If EV with specification as given in Table 5 are considered for the taxi services, it would require a charge cycle of 1.7 per day with total electrical energy requirement of 38 kWh/day/taxi. If one petrol ICEV taxi is replaced by an EV which is charged through the current grid, the carbon emission scenario is shown in Table 6.

The conclusion that can be drawn from Table 6 are as follows:

- $CO_2$ emission in case of EV is 8.86% less than that of ICEVs.
- The major concern of carbon emission in case of EVs is due $NO_x$ and $SO_x$ from the utility grid.
- Since, $SO_x$ and $NO_x$ have high global warming potential values, therefore the net carbon impact is worst in comparison of ICEV.

**Table 7** Carbon emission comparison for EV using current grid and Euro V ICEV taxi running 215 km

| Emission type | Carbon emission in 2030 (grams) | |
|---|---|---|
| | Grid | Petrol ICEV |
| $CO_2$ | 13,860 | 31,605 |
| $NO_x$ | 48.84 | 12.9 |
| $SO_x$ | 108.9 | 0.172 |
| PM | — | — |
| $CO_2$ eq. | 28,402 | 35,475 |

**Table 8** Electricity charging contributions of grid and RE system for one EV taxi

| Configuration | Grid Emission (g/kWh) | Grid energy (kWh) | Renewable energy (kWh) | REF (%) |
|---|---|---|---|---|
| current grid | 2220 | 38 | 0 | 0 |
| grid + RE (Euro III std.) | 1341 | 23 | 15 | 40 |
| grid + RE (Euro V std.) | 933 | 16 | 22 | 58 |

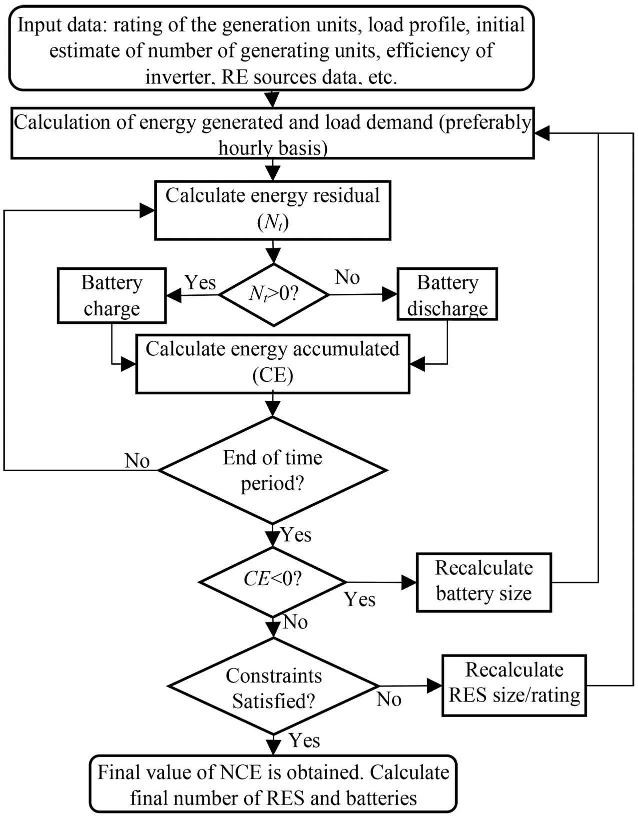

**Fig. 3** *ESCA algorithm flowchart*

- The $CO_2$ equivalent emission in case of EVs is 65.56% more in comparison to ICEVs.
- Under the current grid scenario adoption of EVs is not environmentally friendly.

If the generation mix and carbon emission of the utility is considered as that of 2030 as shown in Tables 1 and 2, the carbon emission scenario changes. For comparison as shown in Table 7, Euro V carbon emission standard is assumed for petrol ICEVs and due to future advancement in EV technology the electricity required for EV in running 215 km is considered 22 kWh [25].

If forecasted utility generation mix for 2030 with above assumptions is considered the EV is sustainable as it produces 20% less carbon emission. But with the current grid scenario the adoption of the EV is not sustainable therefore a solution is proposed in the following section.

### *3.3 Proposed solution*

As per the above discussion, under the current grid scenario EV produces higher emissions than the current Euro III and Euro V standard petrol ICEV. For the EVs to be at par with the current Euro III and Euro V standard, the grid equivalent carbon emission should be 1341 g/kWh and 934 g/kWh, respectively. In order to achieve the grid emission standard for EVs, RE incorporation is proposed. For the current grid emissions to meet the Euro III and Euro V standards a renewable energy fraction 40% and 58% is required respectively. The generation mix, REF and electrical energy contribution for an EV taxi consuming 38 kWh for 215 km is given in Table 8.

In order to achieve the RE penetration, PV battery system is proposed for charging stations. The optimised system size of the RE system for REF of 40% and 58% is found using Electric System Cascade Analysis (ESCA) optimised technique.

### *3.4 ESCA methodology*

Ho *et al.* [26] proposed the ESCA method based on Power Pinch Analysis (PoPA) [27] for optimisation of non-intermittent generators like natural gas, diesel, biogas, etc. Later they also applied ESCA optimisation for single source PV power generation. Zahboune *et al.* [28, 29] have further exhibited that it can be applied to PV-Wind-BESS (Battery Energy Storage System) as well. The basic premise of this method is to find out the accumulated energy and according to fixed constraints recalculate the number of energy sources and energy storage elements. The flowchart showing the working of ESCA for PV-BESS is shown in Fig. 3 [30].

The steps involved for creating a cascade table are shown below [26, 31]:

Column I: The time period of analysis is positioned in ascending order (Hour).

Column II: The hourly load demand is placed (kWh).

Column III: The hourly solar irradiance is placed (W/m$^2$)

Column IV: The size of non-intermittent source for the current iteration. PV energy source generation is calculated using (1).

$$G_t^{\rm PV} = N_{\rm PV} \times R_t \times A \times \eta_{\rm PV} \tag{1}$$

Where, $G_t^{\rm PV}$ is energy generated by PV (Wh), $N_{\rm PV}$ is number of PV panels, $R_t$ is the solar irradiance (W/m$^2$), $\eta_{\rm PV}$ is PV efficiency.

Column V: Net energy demand is calculated using (2) for the PV system

$$N_t = (\eta_{\rm conv.} \times G_t^{\rm PV}) - L_t \tag{2}$$

Where, $N_t$ is the net energy demand (Wh), $L_t$ is the hourly load (Wh) and $\eta_{\rm conv.}$ is the converter efficiency.

Column VI: Charging energy of the battery is calculated using (3)

$$C_t = \begin{cases} 0, & N_t \le 0 \\ N_t \times \eta_{\rm conv.} \times \eta_{ch}, & N_t > 0 \end{cases} \tag{3}$$

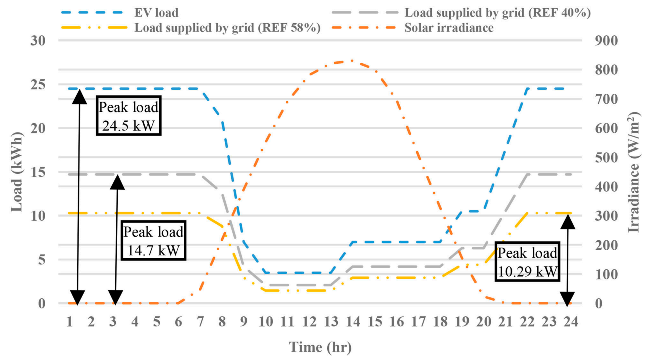

**Fig. 4** *EV load and solar irradiance profiles*

**Table 9** Data required for ESCA

| Parameter | Values |
|---|---|
| duration of analysis | 24 hrs |
| PV type | Mono-crystalline |
| PV efficiency | 15% |
| PV peak power | 250 Wp |
| $V_{\mathrm{bat}}$ | 24 V |
| $I_{\mathrm{bat}}$ | 250 Ah |
| battery charging efficiency | 85% |
| battery discharging efficiency | 85% |
| depth of discharge | 90% |
| inverter efficiency | 90% |

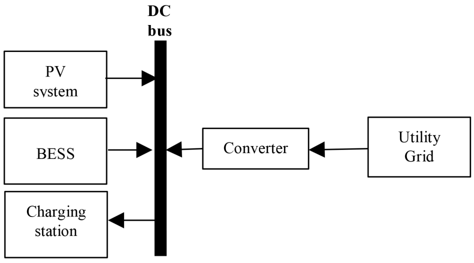

**Fig. 5** *System architecture*

Where, $C_t$ is the charging energy of the battery (Wh) and $\eta_{ch}$ is the charging efficiency of the batteries.

Column VII: Discharging energy of the battery is calculated using (4)

$$D_t = \begin{cases} N_t/(\eta_{\mathrm{conv.}} \times \eta_{\mathrm{dis}}), & N_t < 0 \\ 0, & N_t \geq 0 \end{cases} \tag{4}$$

Where, $D_t$ is the discharging energy of the battery (Wh) and $\eta_{\mathrm{dis}}$ is the discharging efficiency of the batteries.

Column VIII: Cumulative energy in the BESS is calculated using (5).

$$CE_t = CE_{t-1} + C_t + D_t \tag{5}$$

Where, $CE_t$ is the cumulative energy in the BESS for the current time interval.

*3.4.1 Sizing of energy source:* After each iteration if the constraint is not met, the size of the energy source is recalculated using (6–7)

$$\mathrm{EGSS}_{\mathrm{iter}+1} = \mathrm{EGSS}_{\mathrm{iter}} + \frac{\mathrm{FEE}}{T} \tag{6}$$

where

$$\mathrm{FEE} = CE_{t=T} - CE_{t=0} \tag{7}$$

EGSS is the energy generating source size, FEE is the final excess energy, $CE_{t=T}$ is the net energy cumulative after the time period, $T$ is time period of analysis.

*3.4.2 Sizing of BESS (PoPA analysis):* The ESCA iterations is terminated when FEE constraint is achieved. The $CE_{t=0}$ is assumed to be zero signifying that the BESS has no initial charge (for analysis purpose). Once the constraint of FEE is met, the initial charge of the battery is found using PoPA. The pinch point is the time interval at which the $CE_t$ is minimum (negative minimum). This energy is added at $t = 0$ to form the Net Cumulative Energy ($\mathrm{NCE}_t$) column of the ESCA table. The $CE_{t=\mathrm{pinch}}$ is the minimum initial charge required in the BESS and rating of the BESS is calculated by (8–9).

$$N_{\mathrm{bat}} = \frac{\mathrm{NCE}_t(\max)}{V_{\mathrm{bat}} \times I_{\mathrm{bat}} \times \mathrm{DOD}} \tag{8}$$

where

$$\mathrm{NCE}_t = \mathrm{NCE}_{t-1} + CE_t \tag{9}$$

Where, $\mathrm{NCE}_t$ (max) is the maximum value of $CE_t$ after pinch point adjustment, $V_{\mathrm{bat}}$ is the battery voltage (Volt), $I_{\mathrm{bat}}$ is the battery capacity (Ah) and *DOD* is the depth of discharge of the battery.

## 4 Case study

For the analysis of the proposed solution of EV taxi implementation in the city of JNB (26.2041° S, 28.0473°E) in SA is considered. For the first phase of implementation 100 EV taxis with specification in Table 5 is considered. The RE system designed for RE penetration considers PV and BESS which is based on the fact that PV system is cost effective, has no carbon emission and has lower maintenance and operation cost in comparison to Wind and biomass generators which might be other feasible solution. The load profile for charging of 100 EVs, grid contribution for EV charging for two configurations (REF 40% and 58%) and solar irradiance for the site is shown in Fig. 4 [32, 33].

Data required for ESCA analysis is shown in Table 9. The RE system is optimised with FEE constraint and its tolerance is set to +100 Wh. The system configuration of charging station is shown in Fig. 5.

### 4.1 RE system optimised configuration

Firstly, the optimised configuration of the RE system is found for a REF of 40% which makes the EV taxi emission equivalent to Euro III standard petrol ICEV taxi. After successful implementation of ESCA, FEE constraint of +58 Wh is achieved for PV rating 39 kW with battery bank capacity of 127 kWh. The minimum initial charge required in the battery bank for successful pinch analysis with the depth of discharge accounted for is 91 kWh. The power generation by PV and charging-discharging profiles of BESS is shown in Fig. 6. State of charge battery storage before and after pinch point adjustment is shown in Fig. 7. Also, shown in Fig. 8, is the histogram for the BESS.

Secondly, the optimised RE system configuration is found for a REF of 58% which makes the EV taxi emission equivalent to Euro V standard petrol ICEV taxi. On successful ESCA implementation, the PV rating of 56 kW with battery bank capacity of 184 kWh is achieved with FEE constraint of +55 Wh. 132 kWh is the minimum initial charge required in the battery bank for successful pinch analysis accounted with DOD. The power generation by PV and charging discharging profiles of battery is shown in Fig. 9. The state of charge BESS before and after pinch point adjustment is shown in Fig. 10. Also, shown in Fig. 11, is the histogram for the BESS.

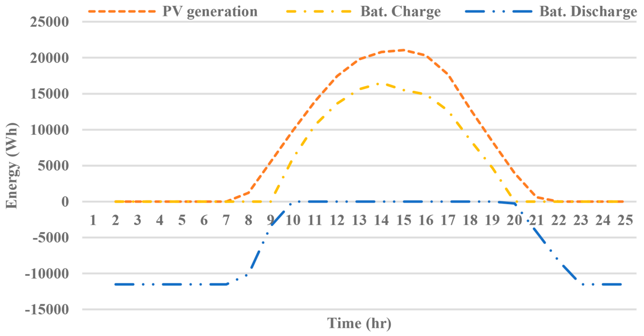

**Fig. 6** *PV generation and battery charge discharge profiles for configuration with REF (40%)*

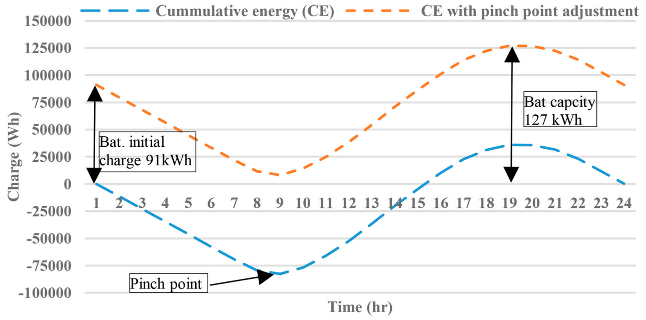

**Fig. 7** *State of charge of battery bank for configuration with REF (40%)*

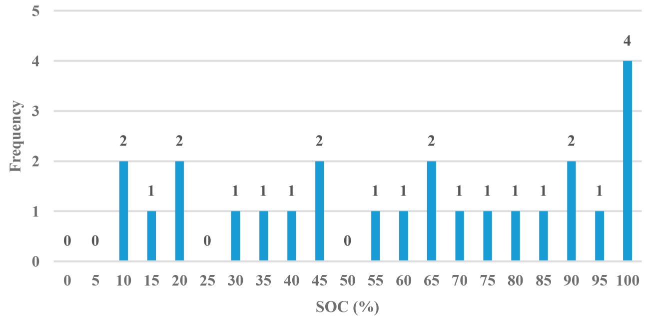

**Fig. 8** *Histogram of state of charge of battery for configuration with REF (40%)*

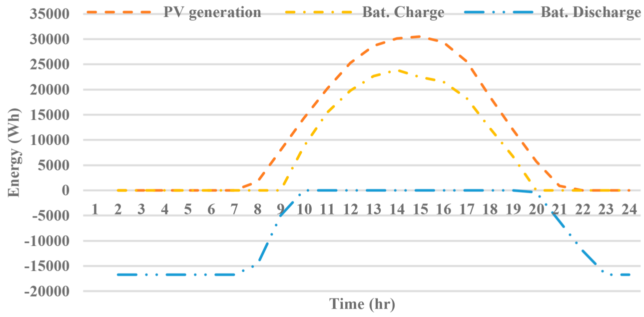

**Fig. 9** *PV generation and battery charge discharge profiles for configuration with REF (58%)*

### 4.2 Results and discussion

The summary of the optimised results obtained for two RE system configuration with REF of 40% and 58% is shown in Table 10.

As seen from Table 10 the rating of PV and BESS increases with an increase in RE penetration. For both configurations slightly higher battery storage capacity is required because of power generation and consumption mismatch as seen from Fig. 4. It is assumed that REF fraction of load is catered by the RE system while rest of the load catered from the utility grid continuously. The charging and discharging trends of the BESS is shown in Figs. 6 and 9 which show during PV generation, EV load is low and hence charging of the BESS takes place. This charge is supplied back to the load during off generation period. The state of charge of battery in both configuration maintains the minimum depth of discharge requirement, as seen from Figs. 8 and 11 the *SOC* does not fall below 10% during the period of analysis. The *SOC* of BESS is depicted in Figs. 7 and 10 which shows that after successful pinch point analysis the charge in the BESS never violates the *DOD* limits. Also, the initial and final charge are almost equal, hence the profile is maintained over repetitive load cycles.

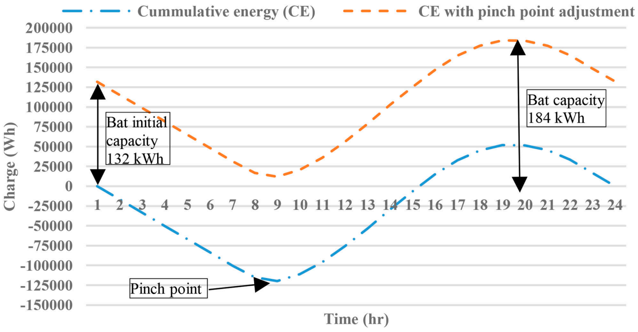

**Fig. 10** *State of charge of battery bank for configuration with REF (58%)*

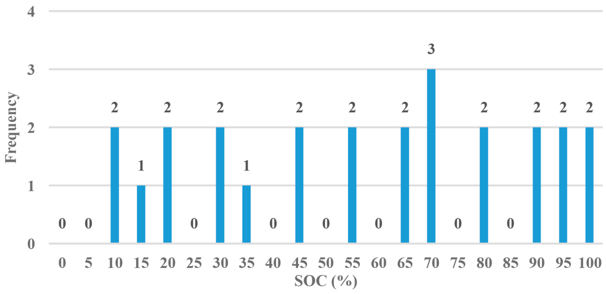

**Fig. 11** *Histogram of state of charge of battery for configuration with REF (58%)*

**Table 10** Summary of obtained results

| Parameters | REF 40% | REF 58% |
|---|---|---|
| PV rating (kW) | 39 | 56 |
| BESS rating (kWh) | 127 | 184 |
| bat. Initial charge (kWh) | 91 | 132 |
| converter size (kVA) | 11 | 15 |
| FEE (Wh) | 58 | 55 |
| pinch point (hr) | 9 | 8 |
| utility charge (kWh) | 216.30 | 151.41 |
| max grid load (kW) | 14.7 | 10.29 |
| euro standard met | Euro III | Euro V |
| carbon emission (g/kWh) | 1341 | 934 |

## 5 Conclusion

It is concluded that as per the current energy generation mix in SA, EV taxi adaption will lead to reduction in carbon emission only if RE resources are included to the charging station. The case study for 100 EV taxis meets the carbon emission of Euro III and Euro V standard petrol ICEV with 40% and 58% RE penetration respectively. With the above-mentioned RE penetration the carbon emission are equivalent to that produced petrol ICEV vehicles, it is preferable to use higher value of REF in order to make EV adoption more environmentally sociable with a compromise on higher system ratings. As per the forecasted generation mix of 2030 which shows increased penetration of RE of 18.7% makes EV sustainable in 2030. It is suggested that in the revision of IRF, EV load should be incorporated in future forecasting for improved sustainability.

## 6 References

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