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Hybrid System Configurations and Charging Strategies for Isolated Electric Tuk-Tuk Charging Station in South Africa

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***Abstract*—**The success of renewable powered electric vehicle charging station in isolated areas depends highly on the availability and sustainability of renewable resources all year round at a selected location. The main focus of this paper is to discuss the possible charging strategies that could be implemented to find the best possible configuration of an electric Tuk-Tuk charging station at a given location within South Africa. The charging station is designed, modeled and simulated to evaluate its performances. The techno-economic analysis of different feasible supply configurations of the charging station using renewable energies is simulated using HOMER software and the results compared in order to select the best possible charging strategies in terms of cost of energy consumed.

***Keywords*—**Electric Tuk-Tuk, Renewable energy, Energy Storage, Hybrid systems, HOMER.

I. Introduction

SOUTH AFRICA's population as well as the economy has grown significantly in recent years, so the demand for passenger transport, electricity as well as private vehicle, water and sanitation has also increased. And it is a well-known factor that the countries transportation sector is facing significant challenges, with the vast majority of rural and township occupants relying on public transport, making this form of transport a critical tool for getting the workforce to and from work. Transportation sector is one of the largest consumers of energy in South Africa and it is vital for economic development, hence making the provision of affordable, safe and reliable transportation of goods and people critical to the development of the country [1], [2].

However traditional ways of transport with combustion engines that rely on fuel will prove to be unsustainable in future because of their carbon foot print and the country's economy, due to the ongoing reliance on imported fuel since most of country's imported fuel fossil is used mainly in the electricity generation and transportation sector [3].

Tuk-Tuks are portable and reliable three-wheeled vehicles which have been used for over 60 years in Asian, European, Central American, South American and in some African countries, and where introduced to South African roads due to their efficiency, stylistic simplicity, low oil consumption, demonstrated flexibility, light-weight, excellent maneuverability and inexpensive operational cost [4]. They are becoming an increasingly common sight on South Africa's roads because people are trying to travel short distances at lower costs than driving and at less risk than walking, and they are providing a cheap solution to the public transportation [5].

However this vehicle also poses a pollution threat due to their inefficient combustion engines, but that could be remedied as research has shown that Tuk-Tuks are relatively ideal for electrification and that could be achieved by replacing their internal combustion engines with an all-electric counterpart [6].

Provision must be made to eliminate the chance of using the country unreliable or inexistent local grid in isolated rural areas, hence a design of a standalone off-grid charging electric Tuk-Tuk charging powered by a hybrid combination of renewable energy sources (such as Photovoltaic and Wind energy) and a battery storage system should be in place to store energy during off peak hours. Therefore, in this paper the techno-economic analysis of implementing such charging stations is conducted for three different isolated locations in South Africa having different climatic conditions.

II. Resource Assessment

Most areas in South Africa average more than 2 500 hours of sunshine per year, and average solar radiation levels range between 4.5 and 6.5kWh/m^2 in one day making its local solar local resource one of the highest in the world [7]. However the country's coastal areas and the Drakensburg Escarpment show the greatest potential for wind energy [8].

For the purpose of this study three sites where chosen, the first site being Mafikeng with the highest solar radiation and low wind speeds, the second being Cape columbine which has moderate wind speed and solar radiation and finally Marion Island which has very high wind speed and low solar radiation and the reason behind this is to assess which system could work well at a site with either resources. Fig. 1 gives an indication of how strong the winds are in the coastal part of the country, and Fig. 2 shows how high is the solar radiation in the northern part whilst Table I shows the tabulated monthly wind and solar resources assessed on the three selected locations.

III. Electric Vehicle Charging Station Overview

There are several operational charging stations presently,

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which correspond to the charging levels detailed in the diagram below, the charging station acts as the point of transfer from grid to vehicle. The majority of the charging operation actually occurs inside the vehicle's on-board charger, where the conversion from alternating current (AC) to direct current (DC) takes place at charging levels 1 and 2, and the battery charge is regulated [9].

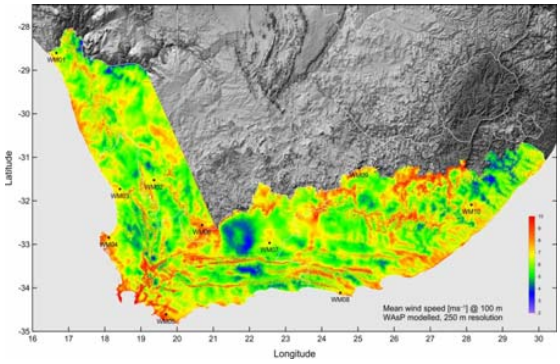

Fig. 1 Wind Energy resources assessment in South Africa [10]

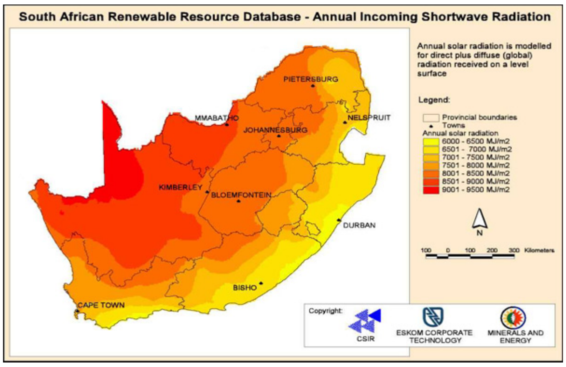

Fig. 2 Solar Energy resources assessment in South Africa [11]

TABLE I
RESOURCES ASSESSMENT AS PER SITES

	Mafikeng		Cape Columbine		Marion Island	
Mon	SR	WS	SR	WS	SR	WS
Jan	10.7	4.8	8.44	6.6	5.12	8.3
Feb	8.8	4.7	7.5	5.9	4.48	8.2
Mar	9.6	4.1	6.22	5.8	3.22	8.5
Apr	10	4	4.66	5.1	2.02	8.0
May	10.2	3.3	3.43	4.9	1.31	8.8
Jun	9.3	3.6	3.01	5.3	0.94	9.3
Jul	9.8	3.1	3.21	5.1	1.11	9.8
Aug	10	4.8	4.10	5.3	1.76	9.2
Sep	10.2	5.4	5.33	5.6	2.65	9.3
Oct	10.8	6.1	6.82	6.2	3.80	8.8
Nov	10.6	6.7	7.96	6.2	4.74	8.4
Dec	8.8	5.9	8.51	6.0	5.21	8.5
Ann	9.9	4.71	5.76	5.7	3.02	8.8

SR- Solar radiation ($kWh/m^2/d$)
WS- Wind speed (m/s)

TABLE II
CHARGING STATION OVERVIEW [9], [12]

	Level1	Level 2	Level 2 /3	Level 4
Places	Home	Workplace	City	City
Types of charging	Home	Semi Public	Public	DC
Charging time	6 -8 Hrs 1Φ 2- 3 Hrs 3Φ	3-4 Hrs 1Φ 1 - 2 Hrs 3Φ	20-30mins	20-30mins
Different modes	Mode1 & 2	Mode2	Mode2 &3	Mode4

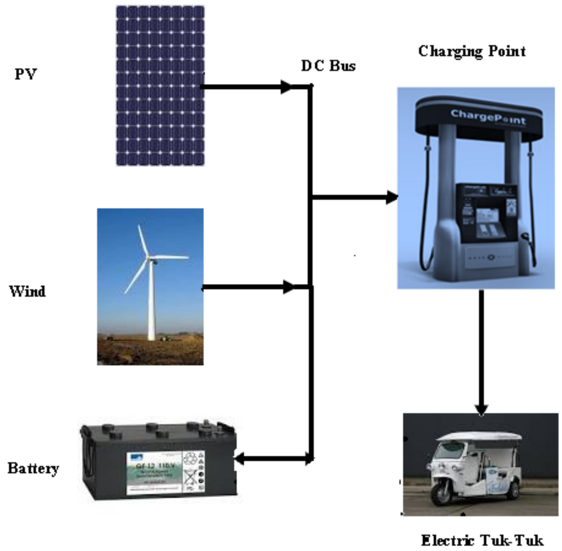

Fig. 3 System layout of a Tuk-Tuk Charging station

IV. SYSTEM LAYOUT AND OPERATING PRINCIPLE

The proposed station will be an off-grid type to avoid putting more pressure on the already distressed local grid, and it will incorporate renewable energies that comprises of solar panels, vertical wind turbines a charging points as well as battery storage system which will be used to store the generated electricity and for battery swapping as shown in Fig. 3. This components should cater for the specified load hence the sizing of this components is very important for the purpose of meeting the daily demand of the electric vehicle charging station. Electricity is generated when the resources are readily available and access electricity is then stored in the battery banks at the charging station, and when the resources are not available then the energy that was stored in the battery banks would then be utilized for the purpose of charging.

V. COMPONENTS SPECIFICATIONS

Table III provides a general description as well as the remarks for the battery parameter. In this study a 12 volts Lead Acid Deep cycle batteries are used and connected in series to provide a 48volts input to the motor used in the Tuk-Tuk.

The battery specifications give a clear indication of how much energy is needed to fully charge a single Tuk-Tuk vehicle in this case the load is 5.76 kWh at a peak of 1.7kW which provides up to 100km range per charge. The specifications of the Electric Tuk-Tuk vehicle are given on the

Table IV.

TABLE III
THE PARAMETERS OF THE TUK-TUK BATTERY [13]

Component	remark
Electric system	12 volts DC battery
Nominal Battery Pack Capacity	120Ah – 130Ah
Number of Modules per Batter Pack	4 connected in series
DC motor controller	48volts
Battery Pack Weight (kg)	130 – 160 kg
Nominal Battery Pack Energy (KW-hr)	5.5 - 6.24

TABLE IV
ELECTRIC TUK-TUK VEHICLE SPECIFICATION [14]

Component	remark
Motor of Electric Tuk-Tuk	1000W / 48V brush DC motor
Power consumption	6-10kw.h/100km (48V)
Max Speed	30km/h
Load Capacity	300kgs
Charging time	6-8H
Charger Capacity	10A
Recharge time	500times
Range per charge	100km-120km
Net weight of Electric Tuk-Tuk	320kgs

TABLE V
COMPONENTS COST

	PV (kW)	Wind (kW)	Battery
Initial Cost ($)	2500-00	4500-00	200-00
Replacement Cost ($)	122	147	566
Operational & Maintenance Cost ($)	150	75	400

VI. CHARGING STATION COMPONENTS SIZING

Charging station components are all the accessories that are employed in the design and implementation of the project.

The selection behind every components size was based on the availability of resources at a certain site and on which size would be best suitable to meet the daily demand that where implemented using three scenarios that would be explained later in this paper. Whilst the prices were checked on the internet from various sources and the replacement as well as the operational and maintenance cost was determined from the simulation that was conducted with aid of HOMER simulation software. Below it's a brief description of the selected component and a tabulated Table V that shows all the component cost in details.

A. PV Panels

A 1kW PV panel price is $2500 in the US, whilst its replacement cost would be $122-00 with its operational & maintenance cost of $150-00 per year.

B. Wind Turbines

The type of wind turbine that was selected for this particular study is a 1kW DC, 48V output. The price for the selected Wind turbine is $4500 in the US and the replacement cost of this component would be $147-00 with its operational & maintenance cost of $75-00 per year.

C. Batteries

A single 12V, 120Ah lead acid deep cycle battery pack is estimated to be $200 in the US with the replacement cost of $566-00 with its operational & maintenance cost of $400-00 per year.

Table III shows a clear and detailed summary of the above mentioned components that would be utilized in the configuration of the electric Tuk-Tuk charging station.

VII. PROPOSED CHARGING SCENARIOS

Three sites within South Africa where chosen with a difference in the resource availability (Solar radiation and wind speeds) and from that the simulation where performed with aid of HOMER for three different proposed scenarios which will be discussed in details in this section of the paper. The focal point of this simulation is to compare all three systems configurations during different scenarios to see which combination (system configuration + scenario) is more suitable to later compare which system is the best above all three. And the comparison criteria for the each system will be based upon the initial cost for that particular system, its net present cost and most importantly the cost of energy (kWh) that could be produced by that system.

A. Scenario 1

Single Tuk-Tuk Charged during the day for 8hours period (S1).This method of charging is when a single battery could be recharged in 8hour duration whilst a driver is using another charged battery to avoid waiting for the whole 8hours and lose profit for not working during that time. The estimated load for that duration is 1.8 kW peak and the energy consumed during that period is 7.7kWh

B. Scenario 2

This case is when a single Tuk-Tuk is charged during the night for 8hours period (S2). This method of charging is an overnight charging when there are no commuters: here a Tuk-Tuk fully depleted battery could be charged up for up to 8hours in the duration of the night. The estimated load for that duration is 1.7 kW peak and the energy consumed during that period is 7.7kWh

C. Scenario 3

This case is when 3 Tuk-Tuks are charged throughout the day for a 24hours period (S3). This method of charging involves back to back charging of 3 Tuk-Tuk for 8hours, each for the whole 24hours in a single day. This option could work well for an owner with 3 Tuk-Tuk's**.** The estimated load for that duration is 1.9 kW peak and the energy consumed during that period is 23kWh

VIII. SIMULATION RESULTS AND DISCUSSION

For a better comparison the results simulated were taken from three different locations within South Africa and subdivided in the three above mentioned scenarios in order to find the best possible solution for each scenario from each system configuration (System 1 – PV panels and battery packs, system2 comprises of wind turbines as well as battery packs and finally system 3 comprises of PV panels, wind turbines as well as battery packs).

A. Site1: Mafikeng

The simulated results for Mafikeng are presented in the table VI below which includes three different scenarios in all three different system configurations followed a comparison of the results to indicate which solution is the best of all three.

If a PV architecture was to be selected for this location the initial cost for such a system would be $5800 with a net present cost of $11562 whilst the cost of energy produced $/kWh would be 0.323 and such a system would comprise of 2 PV (1kW) panels and 4 (12volts) batteries.

If a Wind system was to be considered the Initial cost for such a system would be $61200 with a net present cost of $119480 and a cost of energy produced $/kWh would be 3.336. And such a system would comprise of 12 (1kW) wind turbines and 36 (12volts) batteries.

If a PV-Wind architecture was to be selected for this location the most viable initial cost for such a system would be $10300 with a net present cost of 18549 whilst the cost of energy produced $/kWh would be 0.518 and such a system would comprise of 2(1kW) PV panels, 1(1kW) wind turbine and 4 (12volts) batteries.

Therefore the most cost effective solution for all three scenarios and System is Scenario 1 with system 1, In this case the batteries would be charged up from the station during day when the solar radiation is present and would be collected after 8hours of charging

B. Site 2: Marion Island

The simulated results for Marion Island are presented in the Table VII below which includes three different scenarios in all three different system configurations followed a comparison of the results to indicate which solution is the best of all three.

If a PV architecture was to be selected for this location the most viable initial cost for such a system would be $10700 with a net present cost of $147856 whilst the cost of energy produced $/kWh would be 1.391 and such a system would comprise of 38 (1kW) PV panels and 60 (12volts) batteries.

If a Wind system was to be considered the most cost effective scenarios' Initial cost for such a system would be $7700 with a net present cost of $15983 and a cost of energy produced $/kWh would be 0.451. And such a system would comprise of 3 (1kW) wind turbines and 16 (12volts) batteries.

If a PV-Wind architecture was to be selected for this location the cheapest initial cost for such a system would be $9400 with a net present cost of $17879 whilst the cost of energy produced $/kWh would be 0.504 and such a system would comprise of 1(1kW) PV panels, 1(1kW) wind turbine and 12(12volts) batteries.

The most viable solution financially is a hybrid system for scenario 1 whilst wind system is the viable option for both scenario 2 and scenario 3. Charging would be made with aid of battery banks at the station at night and during the day charging could be made at the station.

C. Site 3: Cape Columbine (LH)

The simulated results for Cape Columbine are presented in the table VIII below which includes three different scenarios in all three different system configuration followed a comparison of the results to indicate which solution is the best of all three.

If a PV architecture was to be selected for this location the most viable initial cost for such a system would be $36600 with a net present cost of $50401 whilst the cost of energy produced $/kWh would be 1.407 and such a system would comprise of 14 (1kW) PV panels and 8 (12volts) batteries.

If a Wind system was to be considered the most cost effective scenarios' Initial cost for such a system would be $11400 with a net present cost of $25853 and a cost of energy produced $/kWh would be 0.772 with a system that would comprise of 2 (1kW) wind turbines and 12 (12volts) batteries.

If a PV-Wind architecture was to be selected for this location the cheapest initial cost for such a system would be $26300 with a net present cost of $53735 whilst the cost of energy produced $/kWh would be 0.501 and such a system would comprise of 5(1kW) PV panels, 2(1kW) wind turbine and 24(12volts) batteries.

Therefore the most cost effective solution is a hybrid architecture this is the most cost effective method in terms of cost of energy produced in $ kWh, however its initial cost is higher than most scenario at this site. In this case charging would take place throughout the day with aid of resource at the station and battery banks would be used for charging during the night and the early hours of the morning.

TABLE VI
SITE1 MAFIKENG

		PV (kW)	
IC	***S1* 5800**	*S2* 6600	*S3* 15700
NPC	**11562**	22347	45101
COE	**0.323**	0.624	0.420
OC	**451**	1232	2300
RC	**1559**	9709	16818
NPVPS	**2**	2	5
NWTPS	**NA**	NA	NA
NBPS	**4**	8	16
		WIND kW	
IC	*S1* 61200	*S2* 67300	*S3* 200000
NPC	119480	123486	378469
COE	3.336	3.753	3.530
OC	4559	5248	13961
RC	28798	30190	92512
NPVPS	NA	NA	NA
NWTPS	12	13	40
NBPS	36	4	100
		HYBRID PV & WIND kW	
	S1	*S2*	*S3*
IC	10300	11000	19400
NPC	18549	28348	47344
COE	0.518	0.791	0.441
OC	645	1349	2186
RC	4133	10606	17571
NPVPS	2	2	5
NWTPS	1	1	1
NBPS	4	8	12

IC- Initial Cost ($)
NPC- Net Present Cost ($)
COE – Cost of Energy ($ kWh)
OC – Operational Cost ($) year
RC - Replacement Cost ($)
NPPS- No of PV panel Per System (kW)
NWTPS- No: of Wind turbines Per System (kW)
NBPS- No: of batteries Per System (12V)

IX. Conclusion

This paper investigated the possibilities of using renewable energies for the design of an Electric Tuk-Tuk charging station in three different isolated locations within South Africa, with different renewable resource (*Solar and Wind*) and the results that were simulated were then tabulated in three different tables for each respective site. The simulations were performed with aid of HOMER and three different strategies were used with one resource configuration (*Solar or Wind*) respectively and also a hybrid configuration of both Solar and Wind.

The simulated results illustrate that the type of architecture depends highly on the availability of resources in a certain Area/site and also on the most cost effective scenario that has lowest cost of energy produced $ kWh for each site.

TABLE VII
Site2 Marion Island

PV (kW)			
S1	*S1*	*S2*	*S3*
NPC	61139	58010	147856
COE	1.706	1.636	1.391
OC	1920	1425	3196
RC	12305	17574	40064
NPVPS	14	14	38
NWTPS	NA	NA	NA
NBPS	8	24	60
WIND kW			
	S1	***S2***	*S3*
IC	11400	**7700**	23900
NPC	25853	**15983**	49170
COE	0.722	**0.451**	0.462
OC	1131	**648**	1977
RC	5884	**4830**	14683
NPVPS	NA	**NA**	NA
NWTPS	2	**3**	1
NBPS	12	**16**	52
HYBRID PV & WIND kW			
	S1	*S2*	*S3*
IC	24355	9400	42200
NPC	36925	17879	61297
COE	0.628	0.504	0.577
OC	892	663	1494
RC	4829	6039	17848
NPVPS	2	1	12
WTPS	1	1	2
NBPS	8	12	16

IC- Initial Cost ($)
NPC- Net Present Cost ($)
COE – Cost of Energy ($ kWh)
OC – Operational Cost ($) year
RC - Replacement Cost ($)
NPPS- No of PV panel Per System (kW)
NWTPS- No: of Wind turbines Per System (kW)
NBPS- No: of batteries Per System (12V)

TABLE VIII
Site3 Cape Columbine

	PV (kW)		
	S1	*S2*	*S3*
NPC	68835	50401	167838
COE	1.923	1.407	1.565
OC	2271	1080	4219
RC	17621	12305	45168
NPVPS	14	14	43
NWTPS	NA	NA	NA
NBPS	24	8	32
	WIND kW		
	S1	*S2*	*S3*
NPC	25853	29812	71504
COE	0.772	0.832	0.666
OC	1139	1378	3497
RC	5644	6540	15169
NPVPS	NA	NA	NA
NWTPS	2	2	4
NBPS	12	16	44
	HYBRID PV & WIND kW		
	S1	*S2*	***S3***
NPC	20975	27110	**53735**
COE	0.585	0.757	**0.501**
OC	722	1323	**2146**
RC	4829	6862	**12264**
NPVPS	2	1	**5**
NWTPS	1	1	**2**
NBPS	8	16	**24**

IC- Initial Cost ($)
NPC- Net Present Cost ($)
COE – Cost of Energy ($ kWh)
OC – Operational Cost ($) year
RC - Replacement Cost ($)
NPPS- No of PV panel Per System (kW)
NWTPS- No: of Wind turbines Per System (kW)
NBPS- No: of batteries Per System (12V)

References

[1] C.Houston "How Decent Public Transport Can Strike a Blow to Poverty 'The South African Civil Society Information Service, 2011, Available @ http://sacsis.org.za/site/article/758.1 /Retrieved 15 June 2013.
[2] www.studymode.com/essays/Transport-Economics-1531117.html Retrieved 23 July 2013
[3] South Africa- Analysis-U.S.Enegy Information Administration: Available @ http://www.eia.gov/countries/cab.cfm?=SF Retrieved 15 June 2013
[4] S Ejaz, A Iqbal, S Rahmanb, FBari, M Ashraf , M Nawaz, C Lim and B Kim, "Toxicological evaluation of the effects of 2-stroke auto-rickshaw smoke solutions on wound healing" Renewable Energy xxx (2013) 1e6E. H. Miller, "A note on reflector arrays (Periodical style—Accepted for publication)," *IEEE Trans. Antennas Propagat.*, to be published.
[5] cheap-cheap tuk-tuk takes over Jozi "South Africa". Available @: http://mg.co.za/article/2013-01-18-cheap-cheap-tuk-tuk-taxis-take-off Retrieved 03 March 2013
[6] Hanaoka S., Acharya S.R., Dirgahayani P., "Mitigating Adverse Impacts of Transport in Asian Megacities" Technical Report of International Development Engineering, Department of International Development Engineering, Graduate School of Science and Engineering, Tokyo Institute of Technology, January 2012..
[7] Wind power and Solar power Available @: http://www.energy.gov.za/files/renewable_frame.html Retrieved 20 January 2014
[8] J.Asamoah "Greening Electricity Generation in South Africa Through Wind Energy" Greenhouse Gas Control Technologies 6th International Conference, 2003, Pages 1349-1352

[9] Kusakana K and Vermaak H "Design of a photovoltaic–wind charging station for small electric Tuk–tuk in D.R.Congo" Renewable Energy 67 (2014) 40-45.
[10] Department of Energy: South Africa "Wind resource maps for WASA domain, South Africa" Available @ www.csir.co.za/ nationalwindsolarsea/WASA_wind%20resource_information _sheet_final_31072013.pdf
[11] White paper on the promotion of renewable energy and clean energy Development: part one-promotion of renewable energy. South Africa: Department of Minerals and energy; 2002.
[12] CEN-CENELEC Focus Group on European Electro-Mobility "Standardization for road vehicles and associated infrastructure. Report in response to Commission Mandate M/468 concerning the charging of electric vehicles", October 2011. Available @: page 25, 26, 34
[13] T. Hofman, S. Van der Tas, W. Ooms, E. Van Meijl, B. Laugeman. "Development of a micro-hybrid system for a three-wheeled motor taxi. In: 24th International battery' hybrid and fuel cell electric vehicle symposium & exposition, May 2009, Stavanger, Norway.
[14] Tremblay O, Dessaint LA, Dekkiche AI. A generic battery model for the dynamic simulation of hybrid electric vehicles. In: Vehicle power and propulsion conference, 9e12 Sept. 2007, Montreal, QB.