SOLAR POWERED TRAFFIC SIGNALS: MYTH OR MARVEL?

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ABSTRACT

This paper evaluates the alternatives available to reduce the power consumption by traffic signals, and to reduce the congestion caused when traffic signals are not operational due to power failures or load shedding by Eskom. Specific attention is given to whether "solar powered" traffic signals is a feasible alternative.

A typical traffic signal consumes 720 Watts with Halogen lamps or 240 Watts with LED lamps. The total power consumption of the estimated 14 000 traffic signals in South Africa, is 10,08 MW using Halogen lamps (0,025% of Eskom's 40 Gigawatt supply), thus a relative small percentage.

By replacing all traffic signal lamps with LED lamps, a saving of 6,72 Megawatt can be achieved, at an estimated capital cost of R700 million. The cost of the power consumption by the 14 000 traffic signals, using Halogen lamps, is R 55 million per annum. This can be reduced to R20 million if the lamps are changed to LED lamps.

The real cost to the economy of power failures or load shedding, is the congestion caused when traffic signals are not operational. If only 1000 of the 14 000 traffic signals are not operational for 2 hours, the additional cost in time delay and fuel, is estimated at R30 million. This is a conservative estimate at typical intersections with moderate traffic volumes.

The alternatives available to reduce the impact of load shedding on traffic signals, is to firstly ensure that no unwarranted traffic signals are erected, or that unwarranted traffic signals are removed (according to the SA Road Traffic Signs Manual).

To provide traffic signals with solar power, a system consisting of solar panels, a regulator, batteries and an inverter is required. This system can only operate with LED lamps as Halogen lamps consume too much power. The hours that the traffic signal must operate autonomous from the batteries, without being recharged by the solar panels, is critical and has a major impact on the design and cost. If the solar powered traffic signal has more than 2 to 3 days of no sunshine (cloudy weather), the batteries will discharge completely and will require outside power to recharge. A medium type solar power installation will cost approximately R250 000 including mitigation measures to prevent theft. Theft of solar panels and batteries is a high risk. To recover the capital cost of the solar panels (in areas where electricity is readily available), with the cost of the power saved, will take an estimated 50 years. To convert all the 14 000 traffic signals in SA to solar power, will cost an estimated R3,5 billion.

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From this paper, ***it is evident that the solution to provide solar power traffic signals as an alternative to Eskom power, is a complete myth***. The high cost is prohibitive, the risk of theft is high and there will most likely be times when inadequate sunlight is available to recharge batteries. A more feasible option is to change all lamps to LED (at say R700 million), which will save 6,72 Megawatt of power. The provision of backup batteries at each intersection is also recommended. The latter will cost R20 000 per intersection, or R280 million for all the 14 000 traffic signals. The LED lamps has further benefits of longer lifespan and the backup batteries will reduce congestion caused during power outages.

1. INTRODUCTION

At the end of 2007 the average South African was unfamiliar with technical jargon associated with energy generation, distribution and consumption. By February 2008 all of that changed as talk of generators, solar panels, and uninterrupted power supplies (UPS), battery backup and wind generation became topics in general conversation. All of this happened as Eskom introduced load-shedding as a form of Demand Side Management (DSM).

One of the negative effects of load shedding has been the congestion caused at intersections with traffic signal control. The real value of a traffic signal is only realized by the general public once it is switched off and traffic comes to a standstill. One of the many debates following the actions by Eskom, is how traffic signals can be provided with power to allow them to continue running during times of load shedding.

Solar powered traffic signals have been proposed as one of the solutions and some Municipalities have already proceeded with installing pilot sites.

The aim of this paper is to place the power consumption by traffic signals in perspective, as well as to evaluate the different alternatives available to keep traffic signals running during times of power failure or load shedding.

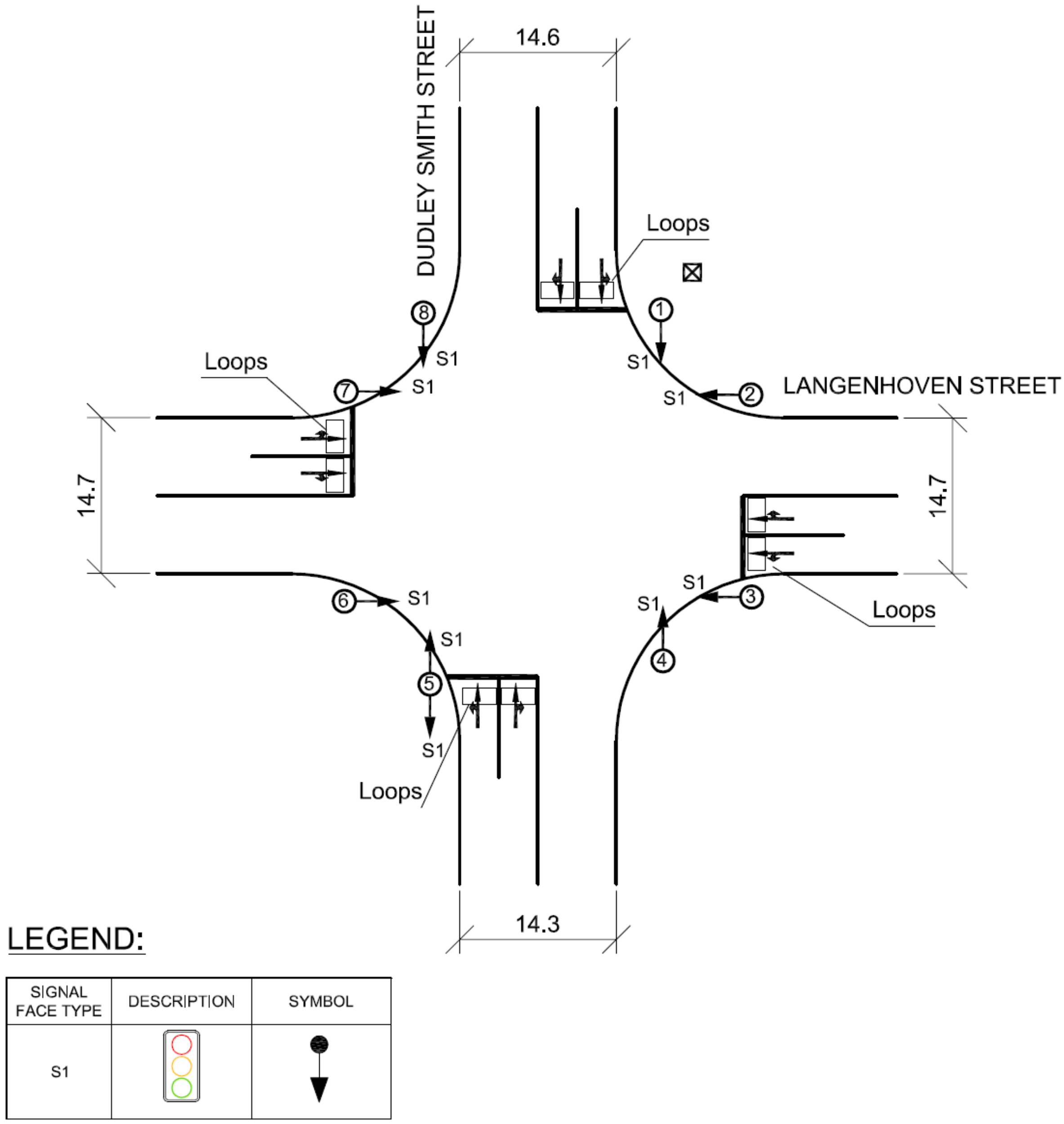
2. TRAFFIC SIGNALS – INTERSECTION LAYOUT AND POWER CONSUMPTION

In order to calculate the power consumption by a traffic signal, a typical layout is defined. The layout of traffic signalized intersections is prescribed by the SA Road Traffic Signs Manual Volume 3 [1].

A large variety in layout and number of signal heads exist – whether an intersection is a T-junction or 4-way, whether it has right-turn phases or pedestrian signal heads, can make a substantial difference in the total power consumption.

For purposes of comparison, a relative simple intersection was used, namely a four-way approach intersection with three S1 aspects facing oncoming traffic from each direction. The figure below shows the typical layout.

During normal operation, three lights will be on per direction (as red, green and yellow can not be displayed at the same time). Therefore at any time a total of twelve lights will be on.



The power consumption of a traffic signal also depends on the type of lamp used. At present, most traffic signals in South Africa still have Halogen lamps, with a power consumption of 55W. LED lamps use significantly less, namely 15 W per lamp. The controller uses approximately 60 watt, independent of the type of lamp used. Table 1 shows the comparison and the total power consumption per intersection [3].

TABLE 1: POWER USAGE BY DIFFERENT LAMP TYPES

Lamp Type	Nr lamps	Power usage (watt per lamp)	Controller power usage (watt)	Total per intersection (watt)
Halogen	12	55	60	720
LED	12	15	60	240
Difference				480

Taking into account that South Africa has approximately 14 000 traffic signals, the total power consumption is as follows:

14 000 traffic signals with Halogen lamps: 10,08 Megawatt

14 000 traffic signals with LED lamps: 3,36 Megawatt

Potential saving: 6,72 Megawatt

LED lamps are at present still relative expensive, with the costs shown below:

Standard S1 Halogen head (red, yellow, green): R 1300

Standard S1 LED head (red, yellow, green): R 2800

This implies to replace 12 signal heads (one full intersection), will cost (material only) R 33 600 per intersection. If labour is added, the total cost per intersection is estimated at R 50 000.

To replace the halogen lamps of 14 000 traffic signals with LED lamps, in order to save the 6,72 Megawatt, will cost R700 million. This is not accurate, as there are already many intersections in the country operating with LED lamps (less than 500) and the actual number of signal heads will differ. The estimate of R700 million does however still provide an order of magnitude of the cost involved to convert to LED lamps.

3. TRAFFIC SIGNAL POWER CONSUMPTION IN PERSPECTIVE

To place the power consumption of traffic signals further into perspective, it should be compared with the total power consumption in South Africa. Various sources quote different numbers, but the capacity of Eskom at present is approximately 40 Gigawatt [2]. There is also an additional 4 Gigawatt needed to supply the immediate additional capacity required. The following table shows the power consumption of traffic signals compared to this:

TABLE 2: TRAFFIC SIGNAL POWER USAGE VS. ESKOM POWER SUPPLY

Lamp Type	Total power consumption of 14 000 traffic signals (MW)	Traffic signal power consumption as % of total Eskom supply of 40 GW	Traffic signal power consumption as % of additional capacity needed by Eskom (4 GW)
Halogen	10.08	0.025%	0.252%
LED	3.36	0.008%	0.084%

The power consumption by traffic signals is therefore a relative small percentage of the total Eskom demand – with Halogen lamps approximately 0,025 % and with LED lamps 0,008 %.

A further element of power supply by Eskom that must be understood is that load shedding is done to reduce their peak demand. If in a household for example, a geyser is switched off at night, it will save the user money on his/her electricity bill, but it will have no impact on Eskom’s peak supply problem.

Similarly with traffic signals – if they are changed to run of battery power during Eskom’s peak load times, it will reduce Eskom’s peak load requirement by a small percentage as shown in Table 2, switching them to battery power during other times will have no impact on the peak demand.

4. TRAFFIC SIGNALS WITHOUT POWER – THE REAL COST

The estimated cost to operate a traffic signal is estimated at between R3500 to R5000 per intersection per year, depending on the number of lamps – and if Halogen lamps are used. This is based on electricity cost of 60 cents per kilowatt hour. For 14 000 traffic signals, this relates to R 55 million per year. If LED lamps are used for all 14 000, the total cost per year will reduce to R20 million (Refer to Section 5.3)

The real cost to the economy is not the cost to operate the traffic signals, but the cost in delays and additional fuel consumption when traffic signals ARE NOT working. Table 3 below shows a basic calculation in which the additional cost was estimated if no electricity result in dead traffic signals, resulting in 1 minute delay per vehicle and assuming 3 more additional stops per vehicle. The result is an additional R 15 000 per hour per intersection, or if 1000 traffic signals are not working for 2 hours – an estimated R30 million for the 2 hour period. (This is regarded as a conservative estimate).

TABLE 3: FUEL AND TIME DELAY COST PER INTERSECTION

Vehicles per hour through one intersection (assumption)	8000
Time cost (R70 per hour) in Rand per second	R 0.0194
Fuel cost per additional stop	R 0.2500
Time cost of 1 minute delay per vehicle	R 1.17
Fuel cost of 3 more stops per vehicle	R 0.75
Total extra cost per vehicle	R 1.92
Per hour (for 8000 vehicles) per intersection	R 15,333.33
Per two hours per intersection	R 30,667
Cost for 1000 intersections for 2 hours	R 30,666,667

5. POWER CONSUMPTION BY TRAFFIC SIGNALS – THE ALTERNATIVES

To reduce the power consumption by traffic signals, the following alternatives are evaluated in this paper:

1. Correct form of intersection control (remove unwarranted traffic signals)
2. Switching traffic signals off at night
3. Change halogen lamps to LED lamps
4. Solar powered traffic signals
5. Provide backup batteries charged when the power is on

5.1 Correct intersection control

Unwarranted traffic signals cause unnecessary delay (and additional fuel and time cost). It also results in an increase in power consumption. The SA Road Traffic Signs Manual prescribe the technical warrants that must be met before a traffic signal can be erected [1]. Many known cases of unwarranted traffic signals exist, where traffic signals are erected for the wrong reasons. Where traffic signals are not warranted, they should be removed and replaced with a more suitable form of intersection control.

5.2 Switching traffic signals off at night – Hypothetical only

Some municipalities operate their traffic signals in “red flashing mode” at night to reduce the delay of individual vehicles stopping, with no real conflicting traffic. This is however not a recommended practice in the SA Road Traffic Signs Manual due to road safety reasons [1].

The following scenario is illegal according to the SA Road Traffic Signs Manual and is only included as hypothetical [1]. An alternative would be to switch off traffic signals at certain intersections between say 22h00 and 05h00 to save power. This is regarded as unsafe from a road safety perspective, as traffic signals are not visible when switched off at night.

The power saved by this alternative will also not reduce Eskom's problem of peak demand and will have a limited impact on the electricity bill of a municipality. Traffic signals use between R3500 and R5000 electricity per year, switching them off at night for 30% of the time will thus save a mere R1500 per year.

5.3 Change Halogen Lamps to LED lamps

As indicated before, changing all halogen lamps to LED lamps will result in an estimated power saving of 6,72 MW. Changing all lamps to LED for 14000 traffic signals, will cost an estimated R700 million.

This is a feasible option, although it will result in a small difference in the total electricity demand of Eskom. It is however supported as LED lamps also last longer and does not have to be replaced as often as Halogen lamps. Lamps that are out create a road safety hazard and reducing the occurrence of lamp failure will result in safer road conditions.

LED lamps can be implemented over time as traffic signals are upgraded. It is foreseen that the cost of LED lamps will also reduce over time as manufacturing cost goes down and the demand for more lamps increases.

5.4 Photo Voltaic (Solar) Panels with Battery backup

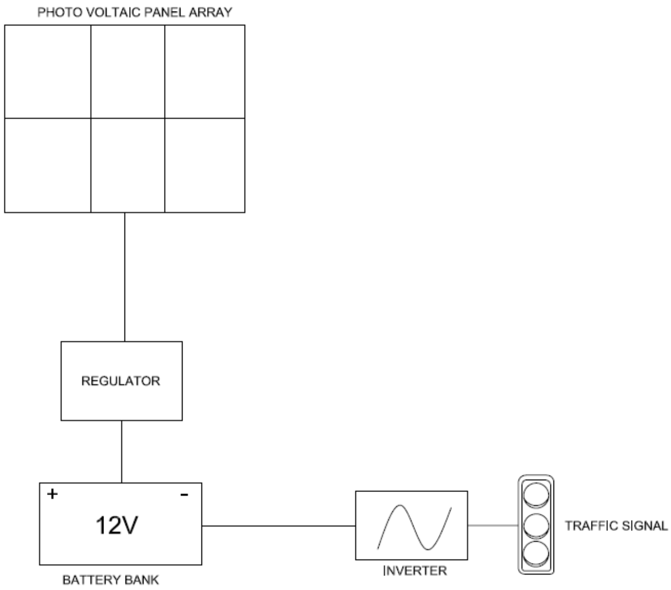
This section is the core of this paper and detail is provided on the different elements of a solar power system.

As outlined below, a solar and battery system with adequate capacity to run a traffic signal with LED lamps, will require a substantial number of batteries and solar panels. As shown before, Halogen lamps will require 3 times more power than LED (720W vs 240W) and is not regarded as a feasible solution with solar and batteries.

A solar power supply system consists of four basic components namely:

- Batteries
- Photo Voltaic (Solar) Panels
- Regulator
- Inverter

The setup is shown in the figure below.



5.4.1 Autonomy

The principle is that the traffic signal must run completely isolated with no electricity supply. The batteries must drive the system autonomous at night and during cloudy days.

Autonomy refers to the time the traffic signal must operate on battery power without the solar panels recharging the batteries. The longest autonomy will be required in winter when the nights are long and the sunshine available to charge batteries is limited. A more critical scenario will however be in the rainy seasons where clouds can prevent charging of the batteries for 2 to 3 – or even more days. This is more critical in the regions of the country with winter rainfall.

The autonomy requirement is a critical design decision and to illustrate the impact of different autonomous times on the number of batteries and solar panels required, Table 5 below was prepared. The critical design scenario is during winter when the hours of sunlight are limited. The sun-hours available vary depending on location and therefore average values are assumed.

The process to design a solar powered traffic signal is as follows:

1. Select the hours autonomy required.
2. Calculate the current (ampere) required during this time
3. Calculate the number of batteries required
4. Determine the number of solar panels required to recharge the batteries with the available sun-hours.

5.4.2 Batteries

Assuming a total of 240 W is required for the traffic signal (Refer Section 2) at 12 Volt, a current of 20A must be available from the batteries. Typical deep cell batteries used with solar powered installations have current ratings of 102 Ampere Hours (Ah). It is recommended by the manufacturers that the batteries should not operate at a depth of discharge (DOD) of more than 60% [5]. This implies at least 40% of the capacity of the battery must remain before it is charged again, as it will substantially increase the lifespan of the battery. To be conservative, this design was done using 50% of the Ah rating, i.e. 51Ah per deep cell battery.

5.4.3 Solar Panels

The number of panels will determine how fast the batteries can be recharged whilst also powering the traffic signal. At present, typical PV panels do not deliver more than 7.5A at maximum power (during daily peak sun hours). In Table 5, two scenarios are shown, namely 6 and 8 hours of sunlight.

The total current delivered from the PV panels per hour must be adequate to:

- Power the traffic signals, which requires 20A
- Recharge the batteries in the available sunlight duration

The above can be written as

$I_m = I_d/t + I_i$ (1)

Where:

I_m = Minimum current required per hour for available sun-hours to recharge batteries and power traffic signal
I_d = Total current discharged during night
t = Available sun hours per day
I_i = Current required by traffic signal

The current requirement for 12 hours autonomy and 6 hours sunlight is then:

From (1) $I_m = (240/6) + 20 = 60A$.
The minimum number of solar panels required to recharge the batteries in 6 hours is then 6 x 60 = 360 ampere ÷ 7.5 = 8 panels. This reflects the calculation done in the leftmost column of Table 5. The other columns were calculated similarly.

5.4.4 Regulator

The regulator controls the current from the solar panel to the batteries. As the intensity of sunlight varies, the current supplied varies and the regulator manages the current to prevent damage to the batteries.

5.4.5 Inverter

The inverter is required to change the voltage from 12V DC to 230V AC as used by the traffic signal controller and the lamps. Typical inverter ratings are 200 to 300W. Since the power consumed by the controller will be 240W, but will vary dependent on the number of phases and thus lamps required, a 300W inverter should be used as a minimum. The choice of the inverter must also consider the functionality of the inverter to disconnect the load if the state of charge (SOC) of the batteries is 50% of maximum.

5.4.6 Solar Power Costs

The following table shows the unit costs estimate related to the above design.

TABLE 4: UNIT COST FOR DIFFERENT ELEMENTS [3]

Item	Unit Costs
102Ah Deep Cell Battery	R 2,000.00
200W PV Panel	R 10,000.00
Pole for PV Panels	R 20,000.00
Inverter	R 2,000.00
Regulator	R 500.00

Table 5 shows a summary of various autonomy requirements and sun-hours available. It indicates for each option the number batteries required, the number solar panels and the associated cost. A budget design to allow for 12 hours autonomy will cost R102 500. If however, there is 2 days without sunshine, the batteries will discharge and will not be able to recover and the traffic signal will be without power. Unless a management plan is in place to recharge the batteries with external generator power, this is not a sustainable solution. A more sustainable solution will be to have 48 hours autonomy, which will cost R252 500, if 8 hours sunlight is available.

TABLE 5: AUTONOMY COMPARED TO NUMBER BATTERIES, PANELS AND COST

Design	Option 1		Option 2		Option 3	
Autonomy (hours without sunlight) - Assumption	12	12	24	24	48	48
Total Ampere hours required by taffic light	240	240	480	480	960	960
Nr batteries required (Ah/0,5/100)	5	5	10	10	20	20
Hours sunlight per day - Assumption	6	8	6	8	6	8
Current required during charge time	120	160	120	160	120	160
Total ampere hours that must be replaced	360	400	600	640	1080	1120
Current per panel (Amps)	7.5	7.5	7.5	7.5	7.5	7.5
Total current provided in nr hours (Ah)	45	60	45	60	45	60
Nr panels (total Ah/current in charge time)	8	7	14	11	24	19
Area per panel (squre metres)	1.2	1.2	1.2	1.2	1.2	1.2
Total solar panel area (square metres)	9.6	8.4	16.8	13.2	28.8	22.8
Cost Estimate (excluding installation, cabling and VAT)						
102Ah Deep Cell Batteries	R 10,000.00	R 10,000.00	R 20,000.00	R 20,000.00	R 40,000.00	R 40,000.00
200W PV Panel	R 80,000.00	R 70,000.00	R 140,000.00	R 110,000.00	R 240,000.00	R 190,000.00
Pole for PV Panels	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00
Inverter	R 2,000.00	R 2,000.00	R 2,000.00	R 2,000.00	R 2,000.00	R 2,000.00
Regulator	R 500.00	R 500.00	R 500.00	R 500.00	R 500.00	R 500.00
Total	**R 112,500.00**	**R 102,500.00**	**R 182,500.00**	**R 152,500.00**	**R 302,500.00**	**R 252,500.00**

5.4.7 Solar Panels – Construction, Theft and Cost

The dimensions of a typical 200W, 7.5 ampere PV panel is approximately 1500mm by 800mm and it weighs 15kg [4]. As shown in Table 5, the smallest installation will be 8.4 m^2 and the largest 29 m^2. A pole and mounting structure that can withstand substantial wind loads will be required to support this, hence the cost estimate of R20 000.

Another aspect of solar panels that must be addressed is the risk of theft. All current solar installations in South Africa are experiencing a high frequency of theft.

An additional cost element therefore is theft mitigation measures such as anti-climbing structures, electric fencing around panels (using an energizer that can work with an inverter and the batteries), epoxy of panels to structures and even the latest technique available - satellite tracking of solar panels.

Batteries are also a high risk item in terms of theft, which will require a steel cabinet or similar concrete structure to secure them. The extra cost of theft mitigation can therefore increase the price of the installation and complicates the servicing of equipment.

If, from Table 5, the typical solar powered traffic signal costs say R200 000 to install, and assume a further R 50 000 is spent on theft mitigation measures, the total cost for solar power supply is R250 000. If the specific traffic signal is in an area where electricity is readily available, it will be more cost effective to provide normal Eskom supply. Assume the operational cost of the electricity is say R5000 per annum, a simplistic calculation shows it will take 50 years to recover the capital cost. This excludes the fact that the batteries will require replacement say every 3 years and does not include the replacement cost of potential theft.

5.5 Provide backup batteries (charged when the power is on)

To keep traffic signals operational when there is load shedding or a general power failure, a battery backup or Uninterrupted Power Supply (UPS) can be provided at each traffic signal. The batteries are charged with the normal electricity supply when on, and the batteries are used only when the supply is down.

The components of a battery backup system include:

- Batteries
- Regulator
- Inverter

Batteries

To provide a 6 hour backup at 20A/hour the batteries must be able to deliver 120A. This can be achieved using 3 batteries.

Regulator

A regulator must be chosen according to maximum recharge current required. Recharging the batteries using the local supply can be done over longer periods of time than the 6 or 8 hours assumed for PV panels. This means less charge current and a regulator that manages 30A will be adequate.

Inverter

A similar inverter to that used for the solar power alternative, will be used.

Battery Backup Costs

The following table summarizes the estimated cost of the battery backup described above.

TABLE 6: COST FOR BATTERY BACKUP ALONE

Item	Quantity	Rate	Total
102Ah Deep Cell Battery	3	R 2,000	R 6,000
Inverter	1	R 2,000	R 2,000
Regulator	1	R 500	R 500
Other	1	R 1,600	R 1,600
TOTAL			**R 10,100**

The price excludes cabling costs and VAT. Assume the enclosure for the batteries to protect it against theft will cost a further R 10 000 per intersection, bringing the total cost to say R20 000.

6. COMPARISON OF ALTERNATIVES

The comparison of the different alternatives to reduce the power consumption by traffic signals can be summarized as follows:

Providing the correct form of intersection control should be a first step. An unwarranted traffic signal should not be erected and where unwarranted traffic signals do exist, they should be removed.

Switching traffic signals off at night or allowing them to flash is not a feasible option from a road safety perspective – it will also not reduce the peak Eskom demand.

Changing halogen lamps to LED lamps will result in a significant saving, but at a high capital cost of R700 million for all the signals in South Africa. It is however supported and should be implemented over time as the lifespan of LED lamps is also longer.

Provision of solar power and batteries to traffic signals, in areas where electricity is readily available, is not a feasible option. It is expensive (between R100 000 and R250 000, typically around R200 000) and presents a high theft risk of batteries and solar panels. The real risk also exists that if clouds prevent the solar panels from charging the batteries for 2 to 3 days, the batteries will discharge completely requiring external power. It is therefore not a sustainable solution.

A more feasible solution will be to provide a battery backup to power the traffic signal in times of load shedding or power failure, which can be provided at a cost of R20 000 per intersection. This will prevent the real significant impact of load shedding, namely the resulting congestion when the traffic signal is not operational.

7. CONCLUSION AND RECOMMENDATION

This paper evaluates the alternatives available to reduce the power consumption by traffic signals, and to reduce the congestion caused when traffic signals are not operational due to power failures or load shedding by Eskom. Specific attention is given to whether “solar powered” traffic signals is a feasible alternative.

A typical traffic signal consumes 720 Watts with Halogen lamps or 240 Watts with LED lamps. The total power consumption of the estimated 14 000 traffic signals in South Africa, is 10,08 MW using Halogen lamps (0,025% of Eskom's 40 Gigawatt supply), thus a relative small percentage.

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8. REFERENCES

[1] South African Road Traffic Signs Manual 3rd Edition, Volume 3, Traffic Signal Design

[2] Various articles, notably the following Eskom Presentation: Adaptation in the Electricity Sector, 19 Nov 2007, Gina Downes, Eskom Corporate Sustainability Department

[3] Power ratings and prices have all been researched from the public domain.

[4] Data sheet of Sharp ND-216U2 Photovoltaic Module

[5] Refer to the following website http://www.windsun.com/Batteries/Battery_FAQ.htm#Lifespan%20of%20Batteries

Batteries

To provide a 6 hour backup at 20A/hour the batteries must be able to deliver 120A. This can be achieved using 3 batteries.

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Switching traffic signals off at night or allowing them to flash is not a feasible option from a road safety perspective – it will also not reduce the peak Eskom demand.

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The real cost to the economy of power failures or load shedding, is the congestion caused when traffic signals are not operational. If only 1000 of the 14 000 traffic signals are not operational for 2 hours, the additional cost in time delay and fuel, is estimated at R30 million. This is a conservative estimate at typical intersections with moderate traffic volumes.

The alternatives available to reduce the impact of load shedding on traffic signals, is to firstly ensure that no unwarranted traffic signals are erected, or that unwarranted traffic signals are removed (according to the SA Road Traffic Signs Manual [1]).

To provide traffic signals with solar power, a system consisting of solar panels, a regulator, batteries and an inverter is required. This system can only operate with LED lamps as Halogen lamps consume too much power. The hours that the traffic signal must operate autonomous from the batteries, without being recharged by the solar panels, is critical and has a major impact on the design and cost. If the solar powered traffic signal has more than 2 to 3 days of no sunshine (cloudy weather), the batteries will discharge completely and will require outside power to recharge. A medium type solar power installation will cost approximately R250 000 including mitigation measures to prevent theft. Theft of solar panels and batteries is a high risk. To recover the capital cost of the solar panels (in areas where electricity is readily available), with the cost of the power saved, will take an estimated 50 years. To convert all the 14 000 traffic signals in SA to solar power, will cost an estimated R3,5 billion.

From this paper, ***it is evident that the solution to provide solar power traffic signals as an alternative to Eskom power, is a complete myth***. The high cost is prohibitive, the risk of theft is high and there will most likely be times when inadequate sunlight is available to recharge batteries. A more feasible option is to change all lamps to LED (at say R700 million), which will save 6,72 Megawatt of power. The provision of backup batteries at each intersection is also recommended. The latter will cost R20 000 per intersection, or R280 million for all the 14 000 traffic signals. The LED lamps has further benefits of longer lifespan and the backup batteries will reduce congestion caused during power outages.

8. REFERENCES

[1] South African Road Traffic Signs Manual 3rd Edition, Volume 3, Traffic Signal Design

[2] Various articles, notably the following Eskom Presentation: Adaptation in the Electricity Sector, 19 Nov 2007, Gina Downes, Eskom Corporate Sustainability Department

[3] Power ratings and prices have all been researched from the public domain.

[4] Data sheet of Sharp ND-216U2 Photovoltaic Module

[5] Refer to the following website http://www.windsun.com/Batteries/Battery_FAQ.htm#Lifespan%20of%20Batteries