# 1. Conventional solution

**Off-grid BTS supplied by 1 or 2 generators, each rated at 7,5 kVA**

## 1.1 Load and fuel consumption

| | Duration (hr) | Load (W) | | Energy (kWh) | | Generator load (%) | Fuel (l/hr) | Duration (hr) | l/day |
|---|---|---|---|---|---|---|---|---|---|
| **Day** | | | | | | | | | |
| BTS + MW | 12 | 1000 | | 12.0 | | | | | |
| Air-conditioning | 12 | 836 | | 10.0 | | | | | |
| | | | 1836 | | 22.0 | 24% | 1 | 12 | 12 |
| **Night** | | | | | | | | | |
| BTS + MW | 12 | 700 | | | | | | | |
| | | | 700 | | 8.4 | 9% | 0.9 | 12 | 10.8 |
| **Total per day** | | | | | **30.4** | | | | **22.8** |

## 1.2 Capital and operational expenses (1 generator 7,5 kVA)

**Capital Expenditures (Capex):**
Generator 7,5 kVA 3 phase **$6,500.00**

**Operating Expenditures (Opex) + equipment replacement costs:**

| | | | |
|---|---|---|---|
| Generator replacement every 2 years, costs per year | | | $3,250.00 |
| (replacement after 18.000 running hours) | | | |
| Fuel consumption, liters per day | | 22.8 | |
| Cost of 1 liter of diesel (including delivery) | | $1.00 | |
| Cost per day | | $22.80 | |
| Cost per year | | | $8,322.00 |
| Periodic maintenance (24/24 operation) | | | |
| Every 250 hr: | oil change (3 liter) | $15.00 | |
| | oil filter | $10.00 | |
| | travel and work | $100.00 | |
| Costs per year (site visit every 10 days, 32x per year) | | | $4,500.00 |
| Every 500 hr: | fuel filter and other maintenance | $25.00 | |
| Cost per year | | | $450.00 |
| **Opex per year** | | | **$16,522.00** |

## 1.3 Capital and operational expenses (2 generators 7,5 kVA)

For reasons of reliabilty, often 2 generators are installed.
Capex roughly doubles in comparison with 1.2.
Opex is similar to 1.2.

## 2. A Hybrid solution consisting of a generator, a Phoenix MultiPlus and a battery

This configuration consists out of: one generator, a 3 Phase Phoenix MultiPlus inverter/charger system and a battery. By using this configuration you can reduce the running hours of the generator by a factor 2 or more. Typically the generator would supply the load and recharge the battery during day time. The inverter/charger would take over during the night; when the air-conditioning is off. In order not to over stress the battery, the calculation below is based on a generator run time of 8 hr per day.

During the night the load is 700 Watt. This will be supplied by the inverter/charger. In addition, the inverter/charger will also supply the load during 4 hours of day time. In case of a 24 V battery, the discharge current would be:

Idn = 700/20 = 35 A during night time (12 hr), and
Idd = 1836/20 = 91 A during day time (4 hr)

For this example we are using a rather low discharge voltage (20 V) in order to take into account efficiency losses in the inverter/charger and cabling.

Total discharge: Cd = 12 x Idn + 4 x Idd = 420 + 364 = 784 Ah.

During the day the generator will supply the load and recharge the battery.
The average recharge current during the 8 hours available will be:

Cd / 8 = 98 A.

And the average power required by the inverter/charger:
Pm = 98 x 28 = 2744 W.

We are using a rather high average recharge voltage in order to take into account efficiency losses of the battery, cabling and inverter/charger.

Battery capacity needed: 1600 Ah (the reserve capacity will also allow for approximately 8 hours MTTR in case of generator failure).

Battery type: we recommend flooded tubular plate lead acid for the best price/performance comparison (this the battery used in electric vehicles such as fork lift trucks).

### 2.1. Load and fuel consumption

| | Duration (hr) | Load (W) | | Energy (kWh) | | Generator load (%) | Fuel (l/hr) | Duration (hr) | l/day |
|---|---|---|---|---|---|---|---|---|---|
| **Day** | | | | | | | | | |
| BTS + MW | 8 | 1000 | | 8.0 | | | | | |
| Air-conditioning | 8 | 836 | | 6.7 | | | | | |
| Inverter/charger | 8 | 2744 | | 22.0 | | | | | |
| | | | 4580 | | 36.6 | 61% | 1.6 | 8 | 12.8 |
| **Night:** | Generator | off | | | | | | | |
| **Total per day** | | | | | **36.6** | | | | **12.8** |

**The amazing result is that although the total energy consumption has increased from 30,4 to 36,6 kWh, fuel consumption has decreased from 22,8 to 12,8 liter.**
The increased energy consumption is due to efficiency losses in the battery, cabling and inverter/charger.
The dramatically improved fuel efficiency is due to better fuel efficiency of the generator at higher load.

## 2.2. Capital and operational expenses, hybrid solution

| | | | | |
|---|---|---|---|---|
| **Capex:** | | | | |
| Generator 7,5 kVA 3 phase | $6,500.00 | | | |
| Tubular plate battery 24V/1600Ah (including automatic watering system) | $3,500.00 | | | |
| 3x Phoenix MultiPlus 24/1600/40 | $2,424.00 | (see note 1) | | |
| VE.Net control and monitoring | $500.00 | (see note 2) | | |
| **Total** | **$12,924.00** | | | |
| | | | | |
| **Opex + equipment replacement costs:** | | | | |
| Generator replacement every 6 years, costs per year (replacement after 18.000 running hours, 8 hours per day) | | | $1,083.33 | |
| Battery replacement every 4 years, costs per year | | | $875.00 | (see note 3) |
| Multi replacement every 8 years, costs per year | | | $303.00 | |
| VE.Net replacement every 8 years, costs per year | | | $62.50 | |
| | | | | |
| Fuel consumption, liters per day | | 12.8 | | |
| Costs of 1 liter of diesel (including delivery) | | $1.00 | | |
| Costs per day | | $12.80 | | |
| Costs per year | | | $4,672.00 | |
| | | | | |
| Periodic generator maintenance (8/24 operation) | | | | |
| Every 250 hr: oil change (3 liter) | | $15.00 | | |
| oil filter | | $10.00 | | |
| travel and work | | $100.00 | | |
| Costs per year (site visit every month, 12x per year) | | | $1,500.00 | |
| | | | | |
| Every 500 hr: fuel filter and other maintenance | | $25.00 | | |
| Costs per year | | | $150.00 | |
| | | | | |
| **Opex per year** | | | **$8,645.83** | |
| 10% capex costs over additional investment | $6,424.00 | | $642.40 | |
| **Total** | | | **$9,288.23** | |
| | | | | |
| **Yearly costs advantage of hybrid solution** | | | **$7,233.77** | |

Total costs has been reduced by more than 40%!

# 3. Additional advantages of the hybrid system

### 3.1. Increased reliability compared to the 1 generator solution

In case of generator failure the system will operate on battery for at least 8 hours (800 Ah battery reserve capacity, discharge current 91 A).

### 3.2. Longer generator engine life due to higher load

When operating at low load, the engine will suffer bore glazing, reducing service life. Replacement intervals therefore may even exceed 6 years in case of the hybrid solution.

### 3.3. Less pollution

Less pollution is the result of lower fuel consumption and better combustion.

### 3.4. Possibility to add solar or wind power

The battery is already there!

### 3.5. Improved control and monitoring with VE.Net

VE.Net enables remote control and monitoring of the inverter/chargers and the generator.

# 4. DC solution

Supplying the BTS directly with the DC from the battery. The inverter/chargers would be replaced by battery chargers.
This would eliminate the capex for 3x Multi 24/1600/40 ($2.240,00). They would be replaced by 2x Skylla 24/80 ($1.846,00).
The costs reduction is not impressive.
The DC supply voltage would range from 20 V (battery discharged) to 34 V (absorption charge). If the BTS needs a better stabilized voltage, the additional costs of a DC-DC converter would result in the DC solution being more expensive than the hybrid solution.

Alternatively, a 48 V battery could be used, if the DC voltage required for the BTS is 48 V.

## Notes

**1. Phoenix MultiPlus 24/1600/40**
Three units are needed, to create a 3 phase AC supply.
Continuous AC output at 25°C: 3 x 1600 = 4800 VA.
Continuous AC output at 45°C: 3300 VA.
Peak output: 9600 VA.
AC transfer switch included in the Multi's.
When the generator is running, the Multi's will automatically reduce battery charge current if needed to prevent an overload of the generator during periods of peak demand by the BTS.

**2. VE.Net**
Needed for timing (8/24 operation of the generator) and monitoring of battery state of charge.
VE.Net can also be used to monitor and control both the Victron equipment and the generator from a central control room.

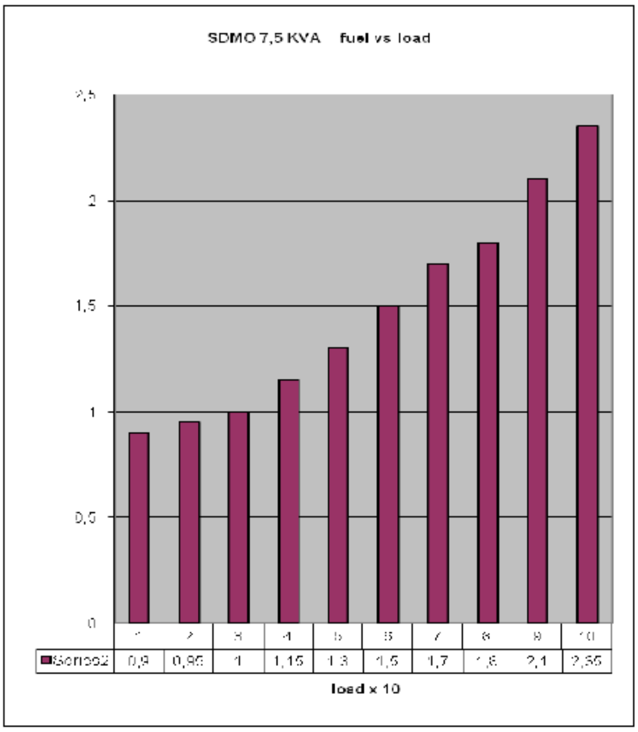
**3. Battery**
The tubular plate lead-acid battery offers the best price perfomance (that is why it is the standard battery for forklifts).

Cycle life
Battery manufacturers claim 1500 - 2000 charge/discharge cycles of 80%, in forklift applications.
This is equivalent to 2400 - 3200 cycles of 50%, which is well in excess of 4 years (4 x 365 = 1460 cycles) service life as assumed under 2.2.
Cycle life is not much affected by temperature.

Float life
Float life is reduced by 50% for every 10°C temperature increase.
Manufacturers claim 10 to 20 years float life for flooded tubular plate batteries, at 20°C ambient temperature.
This would reduce to 5 - 10 years at 30°C ambient and 3,5 - 7 years at 35°C (average temperature)

Service life
End of life is reached when either the max # of cycles is reached, or when the end of float life is reached, whichever comes first.
Battery manufacturers experience and guarantee conditions (and possibly local field experience with electric forklifts) is needed to obtain reasonable certainty that 4 years service life is realistic.

**4. Fuel consumption of generator: see table**

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