ENVIRONMENTAL IMPACT OF AN INDUSTRIAL COMPRESSED AIR SYSTEM WITH A SOLAR POWERED COMPRESSOR IN SOUTH AFRICA

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ABSTRACT
Almost 14% of the electricity generated by the national energy supplier (Eskom) in South Africa is sold directly to the mining sector and almost 20% is utilized directly by the compressed air systems of the mining sector. The industrial compressed air systems in South Africa therefore have a substantial impact on the environment in terms of emissions output. In this paper a solar powered compressor is installed parallel to an existing industrial compressed air system. The environmental (emissions) impact and energy consumption of the industrial compressed air system with the solar powered compressor is calculated and the results are provided. It is shown from the results that the solar powered air compressor improved the overall system efficiency and lowered the carbon footprint of the industrial compressed air system. The impact of the energy improvement on the amount of trees required to offset the calculated amount of CO_2 is also provided.

Keywords: Industrial compressed air, solar power, energy efficiency, emissions impact.

1. INTRODUCTION

According to the national energy supplier (Eskom) in South Africa it is estimated that almost 14% of the electricity being generated is sold directly to the mining sector [1]. It is further estimated that almost 20% of the electricity consumption in the mining sector is utilized by compressed air systems [2]. The use of compressed air is regarded as one of the most expensive methods of energy distribution in mining operations in South Africa [2].

According to a study on the calculation of the carbon capture in tropical reforestation, to offset 29 tons of CO_2 per year for the next 60 years it is required to plant a total of 2334 trees [3]. One newly planted tree therefore only has the ability to binds 12.5 kg of CO_2 per year for a period of 60 years [3, 4, 5].

It is therefore important to investigate the environmental impact and energy consumption of industrial compressed air systems in South Africa. In this paper the scenario where a solar powered compressor is connected to an industrial compressed air system in South Africa is investigated. An overview of the industrial compressed air system is provided together with the applicable tariff structure to calculate the energy savings components. The energy and pressure demand profiles are provided and divided into weekdays, Saturdays and Sundays according to the Eskom Megaflex tariff structure [6]. The results are further expressed in terms of the total monthly energy consumption.

The environmental impact of the solar powered compressor on the industrial compressed air system is expressed in terms of the emissions impact and the total amount of trees required to offset the calculated amount of CO_2. Neale [7] shows what needs to change to secure long-term energy savings of compressed air systems and Al-Mansour [8] provides a comparison of the energy efficiency strategies in the industrial sector.

2. MATERIALS AND METHOD

This section provides an overview of the industrial compressed air system in South Africa and the tariff structure used to calculate the energy saving. For this project the industrial compressed air system near Middelburg (Mpumalanga, South Africa) was selected as a case study. Figure 1 shows a simplified drawing of the industrial compressed air system.

The existing industrial compressed air system has two Centac 5CII 1750 hp centrifugal compressors from Ingersoll-Rand. The Centac compressors are each rated at 1300 kW (or 1750 hp), has a flow rate of 350 m^3/min (or 12,500 cmf) and has a designed pressure of 5.5 – 10.3 bar (or 50 – 150 psig) [9]. The Centac compressors each have mounted inlet, bypass and discharge check valves. The compressors each have an intercooler, after-cooler, oil cooler and are equipped with a microprocessor control system with remote communications capability. More information on the Centac compressors is available in the Centac booklet [9].

The two Centac compressors supply a simplified distribution system consisting of the following three major components: 1) air dryer, 2) air filter and 3) storage air receiver. The air dryer removes the remaining traces of moisture after the after-cooler, since the air required by instruments and pneumatic equipment has to be relatively clean form moisture. The air filter removes contaminants such as particulates, condensate and lubricant and the storage air receiver is used for storage and smoothening of the pulsating pressure variations from the compressor [9]. Regulators regulate the compressed air for use by the user and pneumatic equipment. On the input side of the compressors an Eskom approved digital wattmeter is connected to capture the electricity consumption of the industrial compressed air system.

On the existing industrial compressed air system a solar powered compressor is connected. This compressor is a stand-alone compressor and is not connected to the Eskom grid. The compressor is powered by means of an array of solar panels (photovoltaic) with maximum power point tracking (MPPT); AGM deep cycle solar system batteries; AGM deep cycle advanced glass matte batteries and electronics. The solar powered compressor has a storage air receiver capacity of 30 litres. A control system receives pressure inputs from compressor 1, compressor 2, the storage air receiver and the solar compressor. The control system switches (controls) compressor 1, compressor 2 and the solar powered compressor as required.

Fluri [10] provides results on the potential of concentrating solar power in South Africa and Bugaje [11] provides a review on renewable energy for sustainable development in Africa. From these papers it can be seen that solar power can be a useful source of energy for different applications. Munzhedzi [12] redraw the solar map of South Africa for photovoltaic applications. It is important to take the results of this paper into account, since the available solar radiation per area has a direct influence on the output of the solar powered compressor, which in turn has an influence on the environmental impact of the project. US department of energy [13] and Kaeser compressors [14] provides more information on how to improve and design a compressed air system.

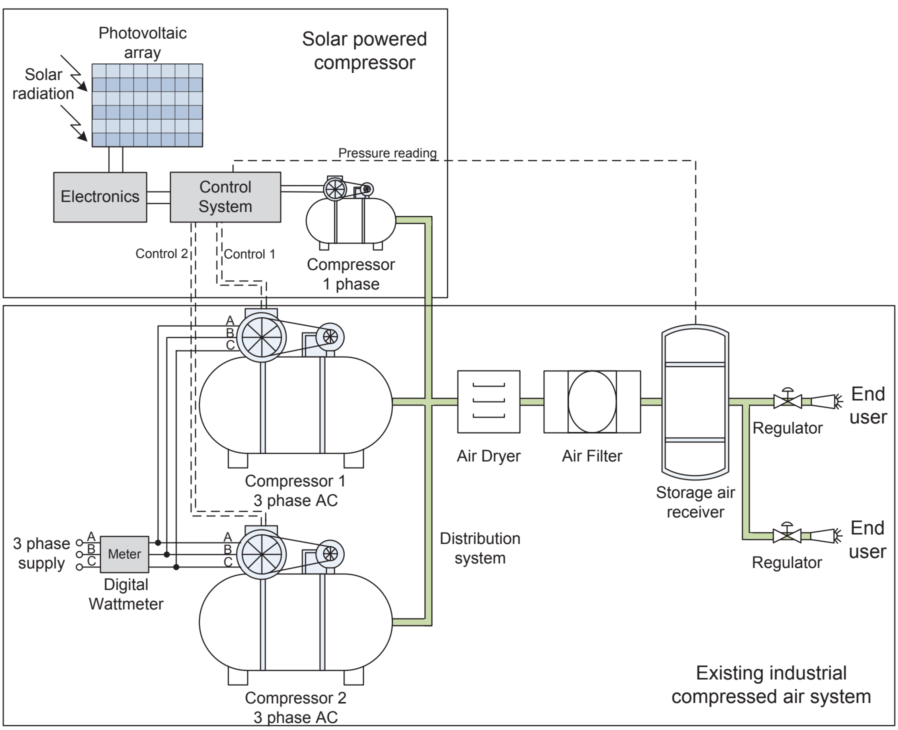

Figure 1. Simplified industrial compressed air system near Middelburg (Mpumalanga, South Africa).

For this project the Eskom Megaflex tariff structure was used and the measurement and verification (M&V) process was done according to the international performance measurement and verification protocol (IPMVP) [6, 15]. Figure 2 shows a drawing of the Eskom Megaflex tariff structure [6]. From this drawing it can be seen that the days are divided into weekdays, Saturdays and Sundays. The weekdays are then further divided into peak, standard and off-peak periods. Saturdays are only divided into standard and off-peak periods and Sundays only has an off-peak period.

For the results obtained from the industrial compressed air system near Middelburg in Mpumalanga (South Africa) the Megaflex tariff structure was used and data was captured over a period of a few months. Eskom approved metering equipment was installed on the industrial compressed air system to capture the data. The solar powered compressor was connected each subsequent week and the baseline and actual profiles were accordingly calculated. Ideally would be to capture data for a period of one year, to take seasonal effects into account. A simulation model of the complete system was then developed and used to obtain energy savings results of the solar powered compressor under rated operating conditions. Baseline service level adjustment was also performed according to the IPMVP [15]. Saidur [16] provide more detail and a review on energy saving and energy use of compressed-air and Kokaew [17] provides detail on a simulation model for a solar powered air compressor.

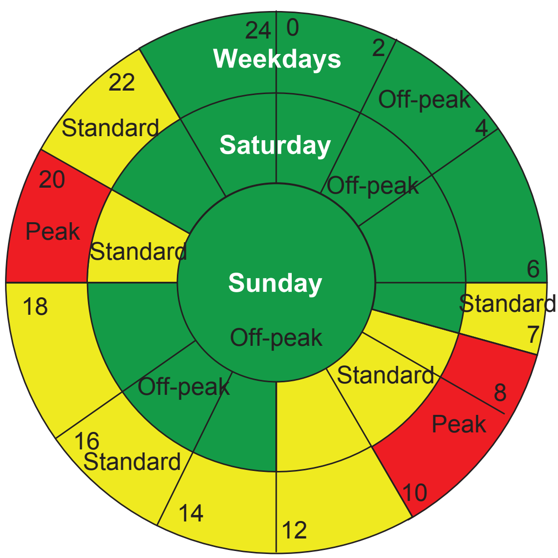

Figure 2. Eskom Megaflex tariff structure.

3. RESULTS

This section provides the results obtained from the industrial compressed air system with the solar powered air compressor. The results in this section were calculated according to the Eskom Megaflex tariff structure. Figures 3-5 show the average weekday, Saturday and Sunday energy demand profiles, with the Eskom Megaflex tariff structure indicators. From these figures the difference between the actual and baseline energy demand profiles are clearly visible. The service level adjustment area is between 00:00-05:00. No difference is visible from 18:00-07:00 in the energy demand profiles, which also correlates with the amount of available sunlight (or solar radiation) during the calculated period. The largest difference (peak area) is visible during 09:00-14:00, which is also the peak solar radiation period for that region.

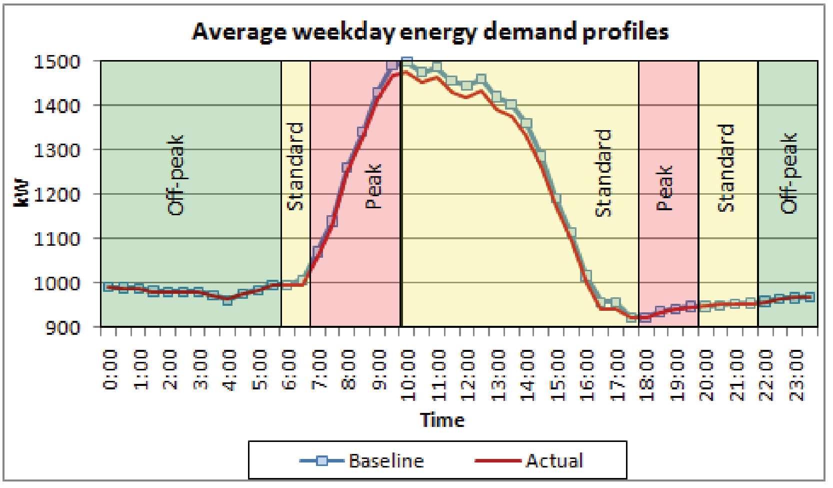

Figure 3. Average weekday energy demand profiles.

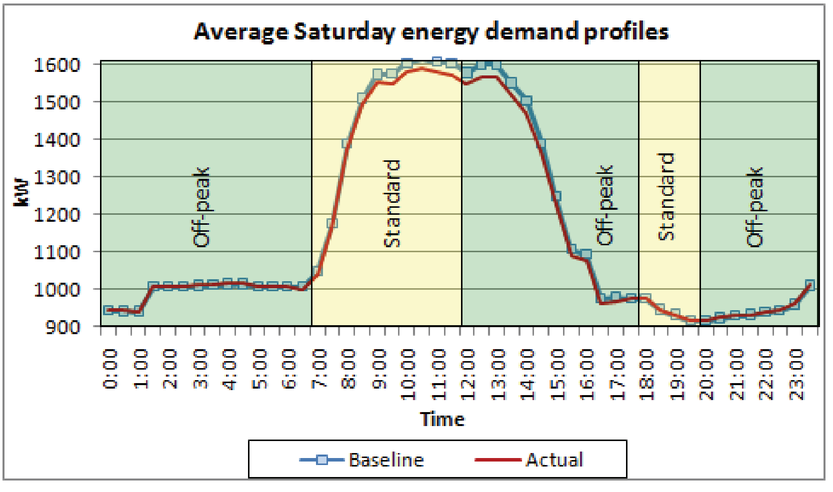

Figure 4. Average Saturday energy demand profiles.

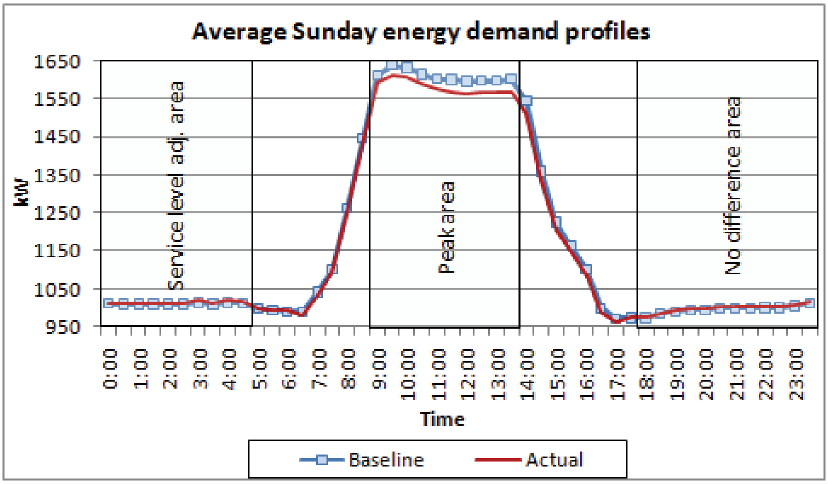

Figure 5. Average Sunday energy demand profiles.

Figures 6-8 show the average weekday, Saturday and Sunday pressure demand profiles, with the Eskom Megaflex tariff structure indicators. From these figures the difference between the actual and baseline pressure demand profiles are clearly visible. The service level adjustment area is between 00:00-05:00. A difference in the pressure is visible from as early as 07:00. No difference is visible from 18:00-07:00 in the pressure demand profiles, which also correlates with the amount of available sunlight (or solar radiation) during the calculated period. Variable differences can be seen in the pressure demand profiles from 07:00-18:00. The peak area as selected from the energy demand profiles are between 09:00-14:00.

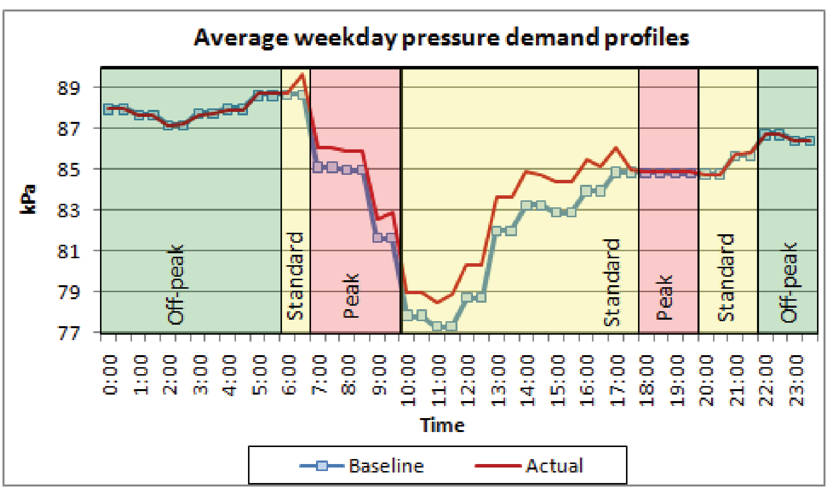

Figure 6. Average weekday pressure demand profiles.

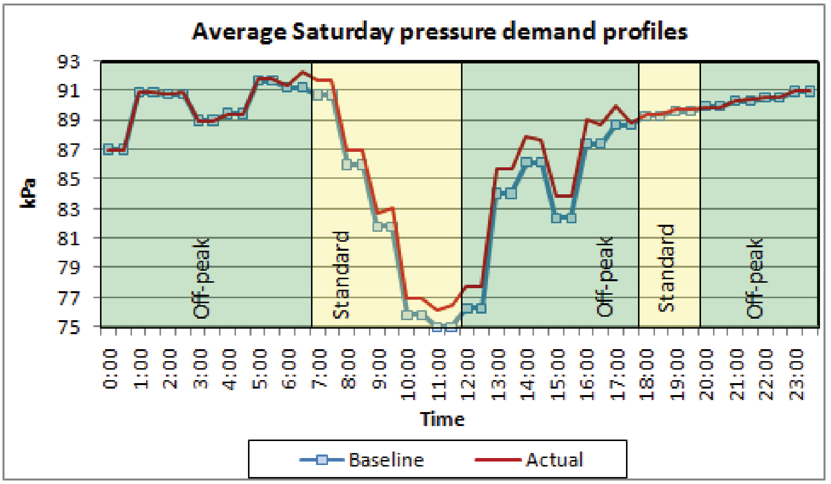

Figure 7. Average Saturday pressure demand profiles.

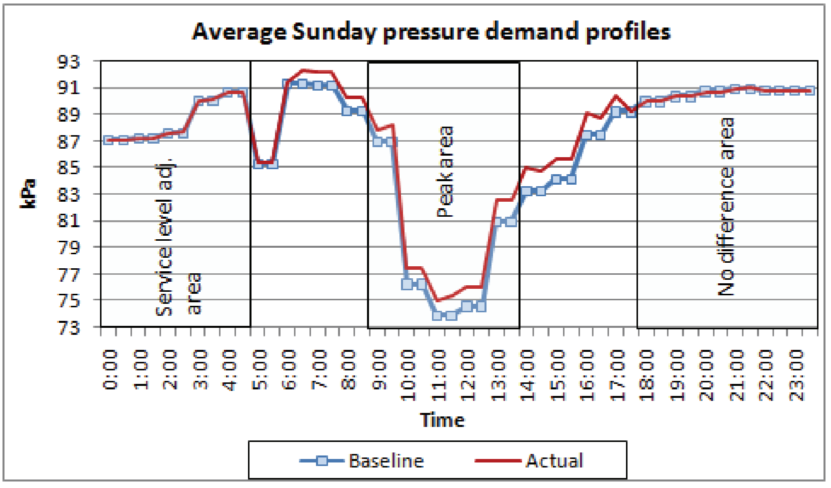

Figure 8. Average Sunday pressure demand profiles.

Table 1 provides the average weekday impact. From this table it can be seen that during the morning off-peak (00:00-06:00), evening standard (20:00-22:00) and evening off-peak (22:00-24:00) periods no impact is visible. During the morning standard period (06:00-07:00) and the morning peak period (07:00-10:00) a total of 0.003 MW (or 0.28%) and 0.008 MW (or 0.59%) was calculated, respectively. The largest impact (calculated at 0.011 MW or 0.89%) occurred during the midday standard period (10:00-18:00).

Table 1. Average weekday impact (MW).

	Morning Off-peak	Morning Standard	Morning Peak	Midday Standard	Evening Peak	Evening Standard	Evening Off-peak
Baseline Demand	0.983	1.003	1.288	1.277	0.938	0.953	0.966
Actual Demand	0.983	1.000	1.280	1.266	0.937	0.953	0.966
Actual Impact	0.000	0.003	0.008	0.011	0.001	0.000	0.000
% Impact	0.00%	0.28%	0.59%	0.89%	0.11%	0.00%	0.00%

Table 2 provides the average Saturday, Sunday and monthly impacts. From this table it can be seen that there is no impact during the Saturday evening off-peak period (20:00-24:00). During the Saturday midday off-peak period (12:00-18:00) the largest impact (calculated at 0.85%) is visible. A total impact of 0.43% is visible during the Sunday off-peak period (00:00-24:00). On Sundays there is only an off-peak period on the Eskom Megaflex tariff structure. The total monthly impact (or total energy saving) was calculated at 0.44%.

Table 2. Average Saturday, Sunday and monthly impacts (MW).

	Saturday Morning Off-Peak	Saturday Morning Standard	Saturday Midday Off-peak	Saturday Evening Standard	Saturday Evening Off-peak	Sunday Off-peak	Total Monthly
Baseline Demand	0.995	1.469	1.299	0.943	0.944	1.174	1.129
Actual Demand	0.994	1.459	1.288	0.942	0.944	1.169	1.124
Actual Impact	0.001	0.010	0.011	0.001	0.000	0.005	0.005
% Impact	0.10%	0.68%	0.85%	0.11%	0.00%	0.43%	0.44%

Table 3 provides the total electricity consumption in MWh during weekdays, Saturdays and Sundays. The weekday, Saturday and Sunday impact was calculated at 2.4 MWh (or 0.42%), 0.6 MWh (or 0.46%) and 0.6 MWh (or 0.42%), respectively. The total electricity consumption resulted in an impact of 3.602 MWh (or 0.43%).

Table 3. Total electricity consumption (MWh).

	Weekday	Saturdays	Sundays	Total MWh
Baseline	560.6	138.8	140.9	840.302
Actual	558.2	138.2	140.3	836.700
Impact	2.4	0.6	0.6	3.602
% Impact	0.42%	0.46%	0.42%	0.43%

Table 4 provides the total emissions (environmental) impact of the solar powered compressor on the industrial compressed air system. The impacts shown in this table is the difference between the baseline period and the actual period. From this table it can be seen that the installation of the solar powered compressor onto the industrial compressed air system, resulted in an average reduction of 3,653 kg of CO_2 per month. An equivalent of 292 newly planted trees is therefore required to offset the calculated amount of CO_2.

Table 4. Total emissions (environmental) impact.

	CO_2 (kg)	SO_x (kg)	NO_x (kg)	Particles	Water (kl)	Trees
Baseline	840,302	3,689	7,302	193	1,210	
Actual	836,649	3,673	7,270	192	1,205	
Impact	3,653	16	32	1	5	292

4. CONCLUSION

This paper provided an overview of the solar powered compressor that was installed parallel to an existing industrial compressed air system in South Africa. The emissions impact and energy consumption of the industrial compressed air system was calculated and the results were provided. The solar powered air compressor improved the overall system efficiency and lowered the carbon footprint of the industrial compressed air system. It is important to take the results on the solar map of South Africa for photovoltaic applications into account, since the available solar radiation per area has a direct influence on the output of the solar powered compressor, which in turn has an influence on the environmental impact of this project. It must be noted that the results were calculated according to the Eskom Megaflex tariff structure. Different impact values on the weekday, Saturday and Sunday energy demand profiles will be calculated if the tariff structure changes.

From the energy and pressure demand profiles, no difference was visible from 18:00-07:00. This correlates with the amount of available solar radiation during the calculated period for the Mpumalanga region. The largest difference was visible during 09:00-14:00, which also falls into the peak solar radiation period for this region in South Africa. The largest impact occurred during the weekday midday standard period (10:00-18:00) and was calculated at 0.011 MW or 0.89%. The total monthly average energy saving percentage was calculated at 0.43% and the total electricity consumption resulted in an impact of 3.602 MWh. The installation of the solar powered compressor onto the industrial compressed air system resulted in an average reduction of 3,653 kg of CO_2 per month, which is an equivalent of 292 newly planted trees. The efficiency of the system can be further increased by installing more solar powered compressors onto the network. The cost of the systems however must be taken into account, when calculating the payback of the project. The environmental and efficiency improvement of this specific solar powered compressor on the total industrial compressed air system will also be higher if installed on an industrial compressed air system with a lower pressure requirement.

A systems approach to reducing carbon emissions, which can also be useful for this project, is provided by Went [18]. Denholm [19] provides more information on the life cycle energy requirements and greenhouse gas emissions for large scale energy storage systems and McHale [20] shows that urban tree plantings can be cost effective in carbon credit markets.

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