PUNCH Power 200 - PUNCH Flybrid's Flywheel Energy Storage System for Power Generation

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Abstract

PUNCH Flybrid, a leading developer of mobile flywheel energy storage solutions, has launched production of its PUNCH Power 200 (PP200) Energy Storage system, for use with power generation equipment. Designed to seamlessly connect to any power grid, PP200 is able to rapidly inject and absorb power to maintain a stable grid frequency and voltage. In the case of dynamically operated diesel and gas generators, these can be downsized by a factor of around two, producing fuel savings of up to 50%. For grid connected applications PP200's power factor correction functionality can be used to reduce the installed capacity by up to 30%.

Introduction

Cost effective and durable energy storage for hybridisation of heavy-duty applications

There is a significant portion and variety of machinery operated under dynamic and arduous duty cycles, typically characterised by long operational hours with frequent high-power and highly transient events. An example of this is a diesel generator powering a crane, as illustrated in Figure 1. The high-power density and durability of a flywheel energy storage system make it ideally suited to the optimisation of such machines. On the other hand, competitor energy storage solutions such as batteries and super-capacitors can suffer from premature degradation and thermal issues - to account for this, they tend to be 'over-sized' increasing their cost further.

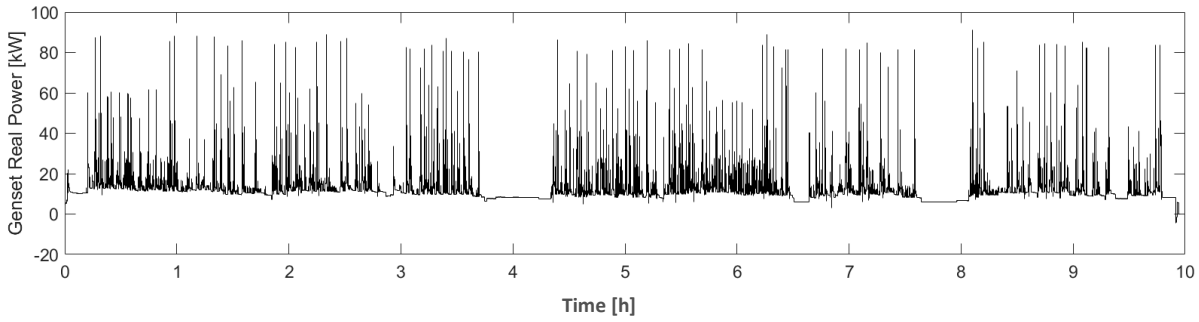

Figure 1: Typical tower crane power demand – low average power with frequent high-power events.

The flywheel can be used to improve machine efficiency in multiple ways. In the case of mobile machinery, it can be used to capture kinetic energy that would otherwise be wasted as the machine

decelerates to a stop or when for example the boom on an excavator is lowered. This recovered energy can then be deployed on the next working cycle to assist the prime power unit of the vehicle to either reduce its fuel consumption or increase its productivity.

In the case of PP200, energy savings are achieved through load-levelling the prime power source, most commonly a diesel engine. By storing energy during periods of lower power demand and deploying this during periods of peak power, the prime power source can be sized for the average load. The downsized power unit will operate at a higher base load and therefore at greater efficiency, in addition to having a lower purchase price and lower maintenance fees.

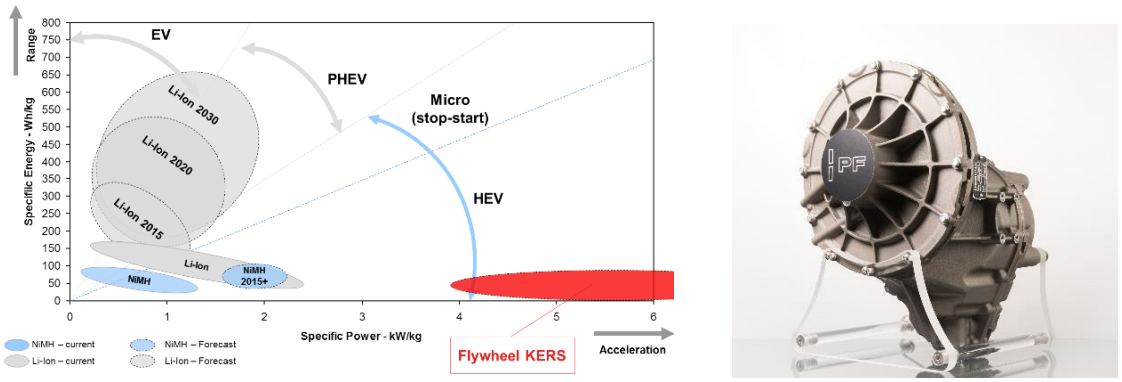

Figure 2: In applications requiring frequent but relatively short high-power energy transfers, power density is key – the flywheel excels at this.

600 Series Flywheel and PUNCH Power 200 - Technology

At the heart of the PP200 system, is a patented flywheel energy storage system designed to fulfil over 80,000hrs of operation, with no degradation in performance. The flywheel module is constructed from materials and techniques widely adopted in the automotive industry making it efficient to produce, ultra-reliable and also gives the flywheel a low embedded CO_2 figure allowing the machine to achieve even greater CO_2 savings.

A key feature of PUNCH Flybrid's flywheel technology is its vacuum seal design which allows the flywheel to run in a vacuum for maximum efficiency, while simultaneously allowing for a shaft type power take-off. This means that the flywheel can be integrated into a machine in different ways, mechanically via a transmission, hydraulically when connected to a hydrostatic pump, or as in the case of PP200, electrically when coupled to an electric motor.

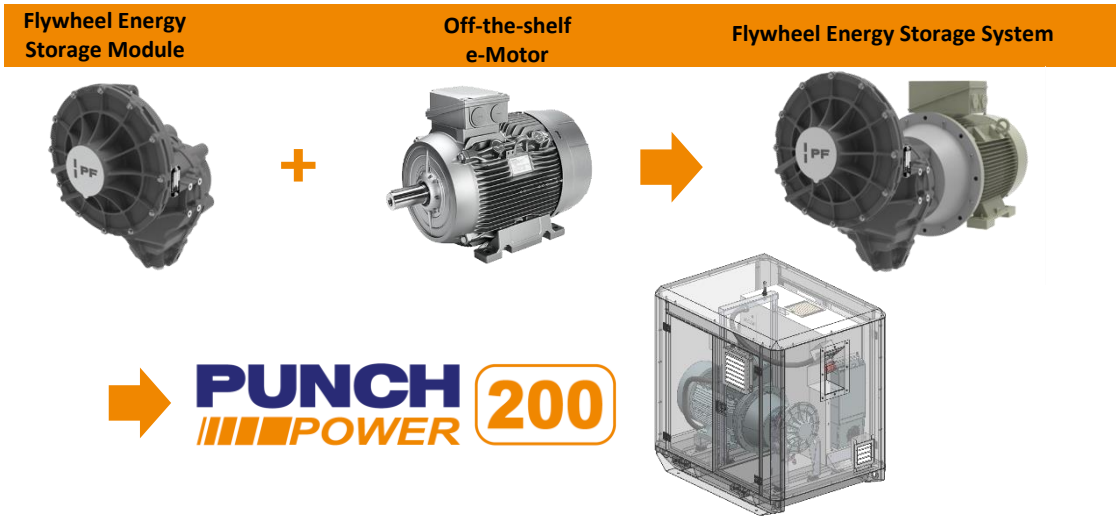

Figure 3: Combination of 600S flywheel module with electric machine and drive to create PUNCH Power 200.

The electric motor is in turn controlled by a variable frequency drive able to achieve power ramp rates of up to 2.8MW/s. Multiple systems can be paralleled up for higher power applications. PP200 connects onto a micro-grid just like any other 'load', requiring no modifications whatsoever to the generator. The on-board power electronics and controllers then monitor the line frequency and voltage to decide when to absorb or inject power so as to optimise the generator operation.

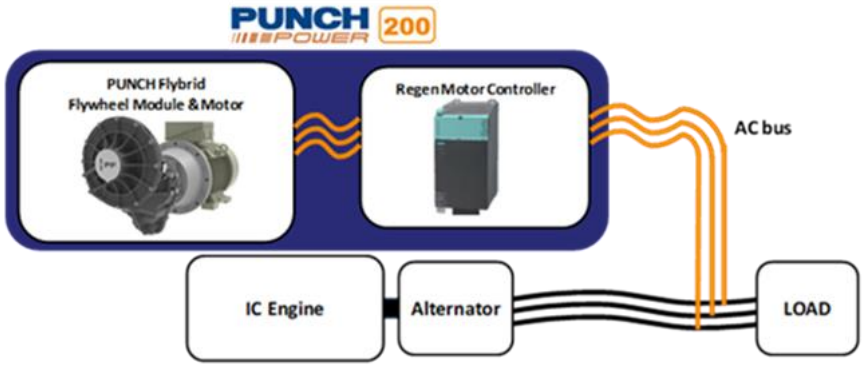

Figure 4: PP200 connection onto micro-grid.

PP200 KEY FEATURES:

- Ultra-fast injection of power to maintain grid stability under dynamic loading
- High specific power
- Long life
- Skid mounted for easy transportation
- Proven and robust technology with a wide temperature operating window
- Seamless connection to grid

Applications

Diesel and Gas Generators

PUNCH Flybrid has conducted field trials with PP200 on numerous applications ranging from pump-jacks on oil production sites to tower cranes on live building sites. In the latter, the required genset rating is traditionally double that of the crane. The oversizing is specified because load steps to 100% of crane power are frequent and most gensets can only maintain an acceptable frequency and voltage response with a 50% load step or less, Figure 5. With PP200 installed, the genset can be 'rightsized' as the flywheel system maintains stable voltage and frequency whilst giving the genset time to achieve the target load, Figure 6.

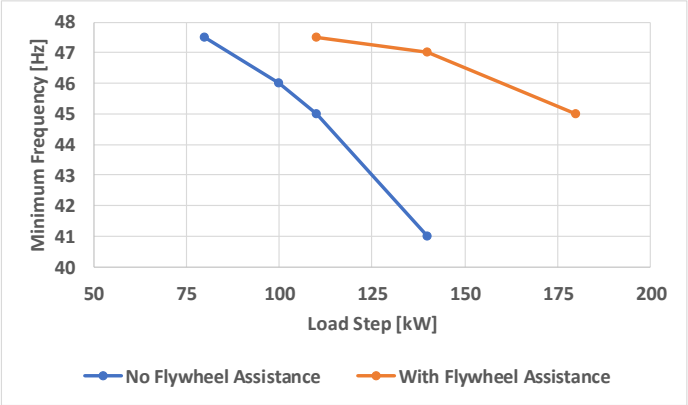

Figure 5: Measured frequency response on a 300kVA genset with and without flywheel assistance. Unassisted, genset frequency drops from a nominal 50Hz to 45Hz during a 110kW (45%) load step and the maximum load step the genset can sustain before stalling is ~140kW (58%), with frequency dropping to 41Hz. With flywheel assistance, frequency drops to 47Hz at the same load and the load step can be increased to 180kW (75%) while still maintaining the genset minimum frequency above 45Hz.

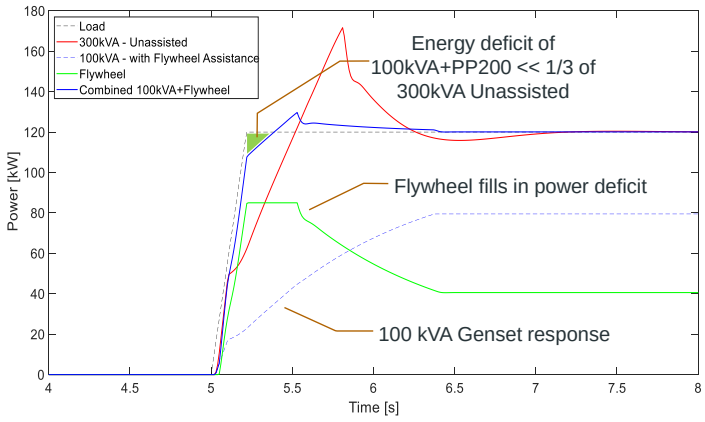

Figure 6: Genset speed (and grid frequency) stability during load transients is governed by the deficit between engine power and alternator electrical load. When genset power is limited (predominantly due to a lag in building the required turbo boost) PP200 injects electrical power reducing alternator load and hence power deficit at the genset crankshaft making up for the smaller engine (and alternator) inertia of the downsized generator.

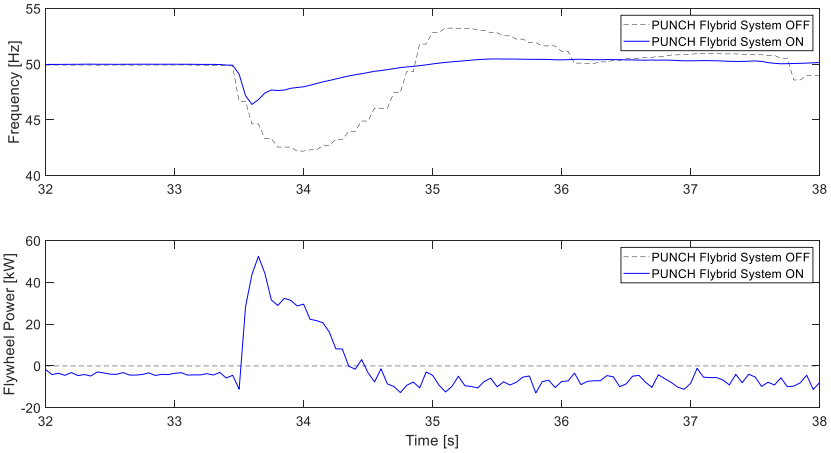

Figure 7: Transient genset frequency behaviour during load step with and without assistance from PP200. Baseline genset frequency drops to ~42.5Hz and needs ~1.3s to recover to 49Hz. With PP200 injecting up to 50kW, genset frequency is maintained above 46.5Hz and recovers to 49Hz in ~0.9s.

Testing has shown that typically the genset rating can be reduced by 50% or more, with similar reductions in fuel consumption, CO_2 emissions and significant reductions of numerous pollutant emissions. On one specific UK construction site, PUNCH Power 200 enabled a 325kVA generator set powering a tower crane to be replaced with a 100kVA generator saving over 240l of fuel per week. This is equivalent to more than 32t of CO_2 saved per year. These benefits will be even greater with the move to Stage V generators due to their requirement to be operated at higher base loads than current Stage III gensets. Furthermore, the changes in Red Diesel taxation will double the fuel cost and therefore will make fuel efficient sizing of generator sets even more important.

Figure 8: PP200 unit supporting tower crane application and on an oil production site.

Similar generator downsizing potential was demonstrated on an oil production site operating 2 pump jacks, one powered from a 75kW variable frequency drive, another with a 45kW direct online (DOL) motor. Originally powered by a 170kW gas generator set, this was replaced by a 70kW generator assisted by PP200. Even with a significantly downsized generator, PP200 reduced the frequency variations significantly, and more importantly the load variations seen by the genset. Operating the smaller genset at a quasi-steady state condition produced very significant reductions in NOx and CO emissions.

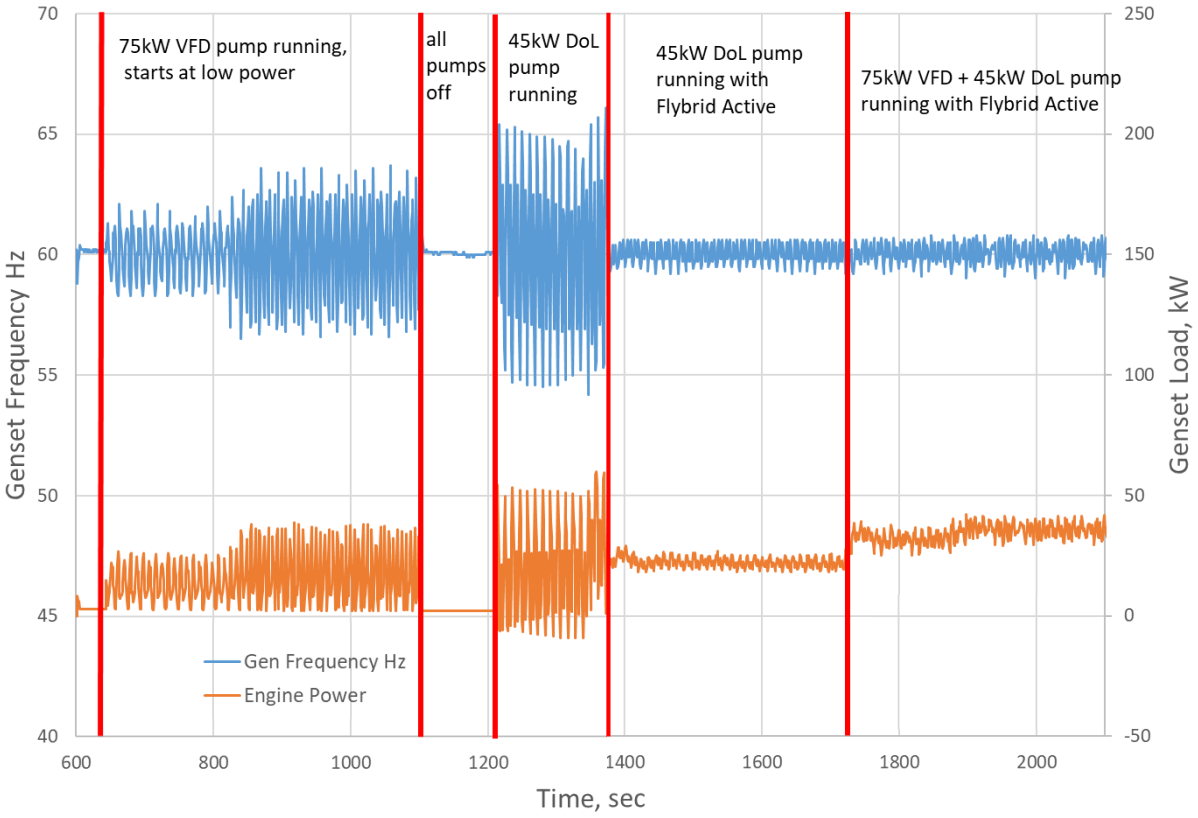

Figure 9: <u>Without</u> PP200 the 70kW genset experiences significant frequency & load variations running either the 75kW or 45kW pumps (the 70kW genset is not able to run both pumps on its own). <u>With</u> PP200 the 70kW genset can run both pumps simultaneously-the frequency variation is also significantly reduced (>50%), as is the power variation (>80%).

System	CO [ppm]	NOx [ppm]
170kW generator set	1019	180
70kW generator set + PUNCH Flybrid	181	15
Reduction	**82%**	**92%**

Figure 10: Significant pollutant emission reductions from downsizing the generator and operating under quasi-steady state conditions.

Renewables – Wind Turbine Power Smoothing

The ability of the flywheel to be rapidly and repeatedly cycled, also makes it an ideal energy storage solution for smoothing power delivery from intermittent power sources, such as a wind turbine. In a particular application the wind turbine was set to target 300kW, but the delay in its control system meant that it regularly overshot this target as wind speed fluctuated. The flywheel system was set to absorb power from the wind turbine when its output exceeded 300kW, and redeploy it when output dropped below 300kW maintaining a more stable supply to grid.

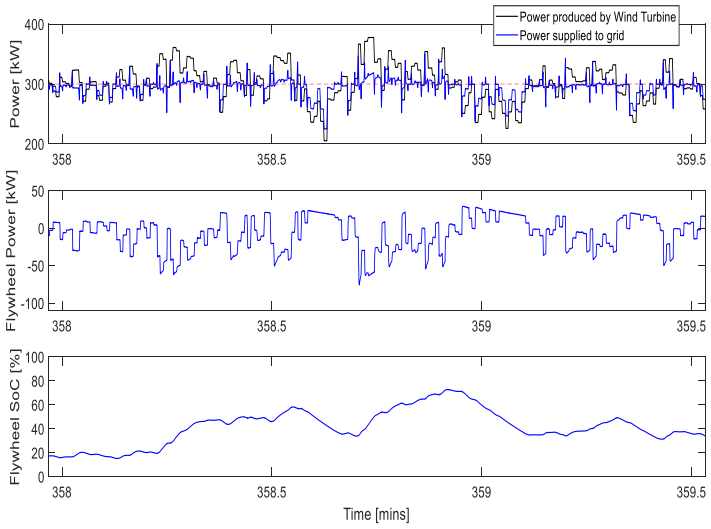

Figure 11: Wind turbine output regularly exceeds limit by up to 25% for up to 5s at a time. With PP200, power exceedances are significantly reduced in both magnitude and duration.

Additionally, the active front end drive incorporated in PP200 allowed it to adjust the wind turbine's power factor as seen by the grid by injecting or absorbing reactive power. The wind turbine power factor varied from 0.98 to 0.96 (inductive) as its output increased from 150 to 300kW. PP200 was used to correct the power factor at the grid to 0.95 as required by the grid operator. It could also increase it to 1 when required.

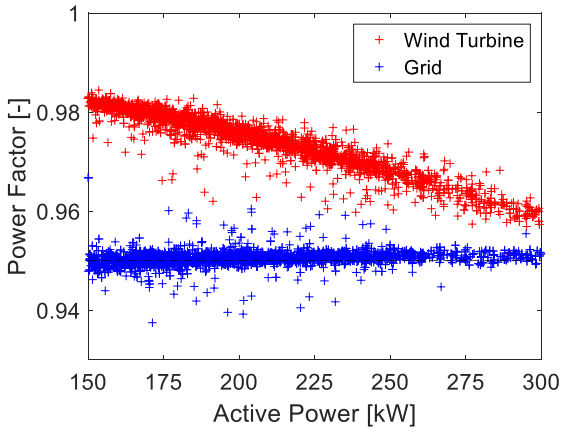

Figure 12: Wind turbine power factor correction example – power factor adjusted to 0.95 at the grid.

Installed Grid Capacity Reduction through Power factor correction

PP200 can also be used to reduce the installed grid capacity at a typical construction site with multiple load types running at different power factors. This can be achieved both through active power injection during large load start-ups and continuous reactive power injection to improve power factor. The presence of large DOL motors on concrete pumps and hoists could be one source of poor power factor that would especially benefit from this particular feature of PP200.

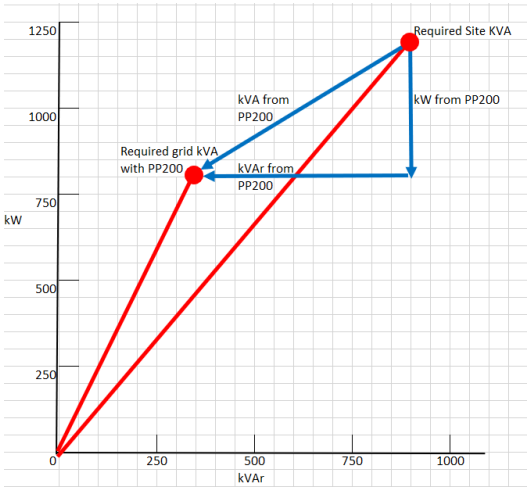

Figure 13: This assumes 5 cranes with ~ 50kVA/ crane over spec and 5xPP200 units each supplying 195A of reactive current – this would reduce the supply by 500 – 650kVA.

PP200 - Future Concepts

A number of developments are planned for PP200 mainly focussed on improving efficiency, cost and the potential to integrate it into even more machine types. Chief amongst these is the shift to a 'direct-drive' design incorporating a high-speed electrical machine with integrated inverter. The elimination of a reduction gear stage will simplify the flywheel module design and improve efficiency further, while the use of a power dense electrical machine will result in a much more compact solution that could potentially be integrated directly into the genset canopy significantly reducing the cost associated with hybridising the genset.

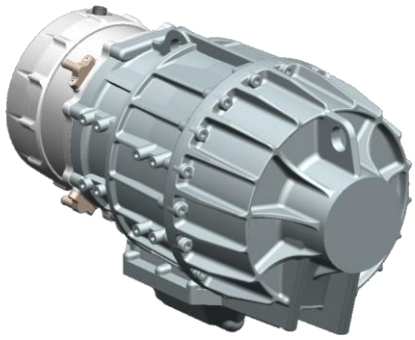

Figure 14: Direct drive flywheel energy storage concept - up to 3x energy of current flywheel module while >50% lighter.

Discussion and Conclusions

With recent years seeing a growing awareness and concern around the negative impact of fossil-fuel based power generation, improving machine efficiency has become more important than ever. This paper has demonstrated that a number of power generation applications can benefit significantly from PUNCH Flybrid's PP200 technology:

- PP200 has shown fuel savings of up to 50% on diesel and gas gensets allowing operators of generators to reduce their operating cost significantly while simultaneously supporting sustainability frameworks through reduction of CO_2 emissions.

- PP200 can be used to smoothen power supply from intermittent energy sources such as wind turbines and simultaneously adjust power factor as required by the grid operator

- PP200's reactive power compensation can also be used to reduce the installed grid capacity requirement on a typical construction site