Low Power Electric Pressure Cookers

Early draft Paper 15/April/2020

This version has now been reviewed and is released for publication

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Working Paper for Comment

Disclaimer – This was an early draft released for discussion among the MECS team, and was originally not intended for publication. However, the information contained has proven useful for partners and collaborators and we now wish to place it on our website for wider use. (June 2021)

This material has been funded by UK Aid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.

1 Introduction

This paper considers the use of silicon controlled rectifier (SCR) voltage regulators as a mechanism for reducing the power consumption of an individual electric pressure cooker (EPC) appliance.

The investigation began as exploration of any mechanisms for creating a low power appliance from a commercially available appliance. An alternative strategy is to manufacture a lower power EPC appliance and that strategy is being explored. However, here we consider whether modifications can be made to the 'delivery' of the electricity such that a commercially available EPC behaves as though it were a lower power appliance. It seems to us that SCR regulators may have some potential and it may have an auxiliary application in terms of mitigating the peak load on a wider electrical system.

Key Research Question:- Can auxiliary/additional devices, placed between plug and appliance, convert a 'higher power' EPC to a 'lower power' EPC without modifying the commercially available EPC and without compromising any of its inherent safety systems?

This document has been made to communicate the basic concept and share with research partners the possibility that while we work towards lower power EPC appliances with the manufacturers, there may be ways we can pilot and prototype systems by using SCR voltage regulators.

It can be shared as an open resource and any researcher or interested party is welcome to use the ideas as a launch to further explore the resulting conclusions, or to pushback where the existing research fails to address a concern. As well as the official UK Aid disclaimer above we acknowledge that these thoughts are incomplete and any organisations using the following discussion to further their work must rely on their own enquiries and due diligence as to the suitability of any research outputs, products or services provided by any third parties and MECS, and the institutions funded to run MECS shall have no legal liability to any party for any losses flowing from any third party's research, products or services.

1.1 Six litre 1kW EPC appliances

Most 6 litre electric pressure cookers use 1kw or above in their heating coil. This gives a cooking experience that their current sales to the developed economies (8 million units per year) suggests is a sweet spot for the speed of cooking. Most advertising for EPCs points to 'speed and convenience', and so 1kw presumably is considered by appliance manufacturers and designers as an optimum for heating the food, holding it at pressure and cooking it 'tastily' with minimal risks of burning, in a timely fashion acceptable by consumers in developed economies[1].

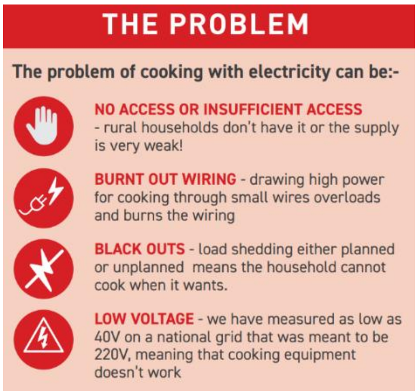

Figure 1 Extract of eCook infographic Gamos 2017

When we consider EPC appliances for Low and Middle Income Countries (LMIC), the MECS programme is exploring the use of EPCs for four key markets as defined by their access to electricity.

- national grids,
- weak national grids
- islanded or limited infrastructure grids,
- solar home systems.

Figure 1 summarises some of the challenges of cooking with electricity in LMIC markets.

[1] The Working Paper "Mash, Beans, Viscosity and Power in Electric Pressure Cookers" (Batchelor 2020), suggests it is quite hard to 'burn' food because of the absence of steam escaping and drying out the food. Quite hard but not impossible.

1.2 Why lower the power?

Burnt out wiring - drawing high power for cooking through small wires overloads and burns the wiring

There are potential challenges in all the markets, more so in the latter three, however even the national grid connections can be compromised by poor wiring and inadequate domestic connections.

High current draw through wiring that is not designed for such could cause tripping of fuses and maybe even burnout of wiring. This would apply to users who have not installed their connections to code, such as those who might be drawing their electricity from their landlords' house via an improvised connection, or those in informal settlements. **Reducing the power of an individual appliance might mitigate the make or break of its use on these poor connections.**

Spike peak loads on a system from multiple appliances

When too many appliances come on at once, the high power can cause spike peak loading which might disrupt the wider system. This 'spiking peak load' can happen even on strong national grids as evidenced by the UK spikes during the half time of the 1990 semi final of the world cup; a majority of households in the UK all switched their kettles on at once![2].

For the problem of peak loading, there are two key strategies:-

- ensure the appliances cannot all come on at once, or
- make sure they are all lower in power.

A solution is to ensure that many appliances cannot all come on at once, and we are working towards such solutions with control systems integrated with mini grids, and even conceptually smart meters integrated with larger grid systems. The concept has been proven by community engagement whereby in Myanmar communities on a mini grid have a simple volt monitor and agree contractually not to switch on appliances if the voltage is low. Such a response is being incorporated into software and hardware of systems to create the same effect so that only a fixed number of devices can operate at once. Research is ongoing.

There is also exploration of 'micro switching' whereby one or several appliances may come on for micro periods synchronously – so for the micro period that one set of appliances are switched off, a different set of appliances on the system are switched on. The food is raised to temperature more slowly, and the experience of the appliance is one of a lower power device. Rapid cycling is something EPCs do at various points in the cooking cycle often based on thermostats to ensure the food does not over heat. These switching responses could potentially prevent too many devices coming on at once and overloading the system.

While the SCR is being investigated here as a mechanism to reduce a single appliance to lower power, they may hold a key for ensuring that a set of appliances cannot all come on at once? **Nevertheless for this paper the question of mitigating peak loads is perhaps answered not by smart metering or pulse synchronising across many devices but ensuring that the appliances are as low power as their use can tolerate.**

Don't ask too much from Batteries

For all the market segments, one possibility for mitigating the high power draw (and mitigating unreliable energy availability) is to use energy storage. This is particularly important for weak grids and off-grid solutions, but can be a strategy even for addressing the problems of low quality wiring and poor domestic electric infrastructure. Trickle charging energy storage means drawing low currents (mitigating the problem of poor wiring), at any

[2] https://www.drax.com/technology/7-of-the-biggest-tv-moments-in-uk-electricity-history/

point during the day or night (mitigating the peak loads) and enabling the user to cook with a high power device whenever they want. This is particularly good for grids reliant on renewable energy (particularly solar which has certain times when energy is available) but also for islanded mini grid and off grid home systems. Figure 2 summarises some of the potential benefits from using energy storage.

While energy storage is helpful, it may also constrain maximum power rates. **Many batteries do not like high discharge rates so even in an isolated home system, minimising the appliances power requirement could be useful.**

Research question

All these challenges formed the basis of this set of experiments – in the absence of commercially available EPCs rated at less than 1 kW, **could lower power EPCs be created from commercially available EPCs?**

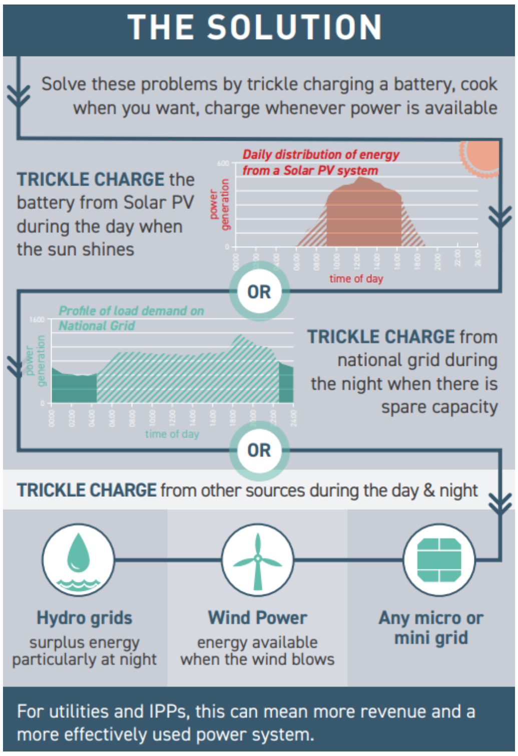

Figure 2 Extract of eCook infographic Gamos 2017

1.3 How low is low?

As previously stated in Working Paper “Mash, Beans, Viscosity and Power in Electric Pressure Cookers”, when visiting China (before Christmas so before virus), I met with Mr Gao, lead designer of Midea. Midea are of course one of the leading manufactures of EPCs.

We asked them if they would consider manufacturing a 600W version of the 6 litre EPC. Our understanding was that most 6 litre (or more) versions are 1 kW or more, and that there are 3 litre versions produced at around 700W, but our research to date suggest 3 litres is too small a pot for Africa and low income Asia.

In our request for a 600W 6 litre EPC Mr Gao had two pushbacks. His first was that the flow of steam through the safety valve would be insufficient to shut the valve. The second pushback was that with low power and a significant amount of cooking material, a 600W device would create a situation where the top and bottom of the material were at different temperatures and were cooking for a different period of time (potentially affecting the taste across the whole).

These pushbacks seemed reasonable and so we have undertaken some experiments to test this hypothesis. In the Working Paper “Mash, Beans, Viscosity and Power in Electric Pressure Cookers” Batchelor 2020, we explore the second of these pushbacks. For the first, that paper suggests that the valve could be shut at the start of the process, thereby eliminating the need for the flow of steam from boiling food to shut it.

The conclusions of the paper was that the concerns may prove to be ill founded and are true only for certain foods. Given its desirability for the reasons stated at the start of this paper, we are pursuing the design and production of a lower power EPCs with sufficient volume in their pots for the African and low income Asian markets.

In this paper I use the method used in “Mash, Beans, Viscosity and Power in Electric Pressure Cookers”, to explore system conversion of 1 kW EPC to a lower voltage EPC.

I state this is a 'system conversion'. It is not changing the EPC appliance, rather it is inserting a voltage regulator between the AC delivery and the appliance to create a lower voltage. I am not suggesting this is definitely the way forward. Rather I am presenting some exploration of devices to create discussion about system designs. [3]

2 Method

The appliance in question was an Instant Pot IP Lux rated at 1kW. To bench mark the concept, a Bronson 3000 variac was used to lower the mains voltage applied to the device to simulate a 600W EPC. Note while the power axis in the following charts shows 620W consumption, approximately 20W was lost to the variac. Two SCR devices were substituted for the variac, and the experiments repeated.

The following graphs show temperature profiles monitored by an ibutton temperature sensors within the pot. The sensor sampled the temperature every 5 seconds.

The green line represents the power drawn (as measured by a Energenie Plug monitor) by the variac and SCR, and shows the device switching on and off. The power is also sampled every 5 seconds, and tends to vary plus or minus 3 to 5 Watts. Note, often after prolonged power off within the cooking cycle, the power tended to come on at between 5 to 10 Watts higher or lower than its initial setting – this is assumed to be an effect of temperature in the circuits?

2 litres of cold water was in the pot at the start of each run. The EPC button programme that was labelled 'Soup' was used at the recommended 30 minutes. Timings were started when the water reached 42 degrees – in order to ensure that all timings were comparable and not affected by the initial variance of water and room temperature. Given the EPC is set to do a pressurised cook for 30 minutes, the total 'cooking' time is defined by **when the EPC switches the timer off** – note this may **not** correspond with when the last bit of power is applied and switched off. Note, the valve shuts at 100 degrees and the heating element remains on until the pressure and temperature in the pot reaches the trigger to set the timer going. 'Cooking time' is in quotes because a) we started at 42 degrees to ensure the same start point, and b) the pressurised chamber would continue to cook any food in it, and therefore the finish point would vary depending on losses.

All graphs show a single run, but all data was repeatable plus or minus a few minutes, and plus or minus a few degrees.

Figure 3 shows the setup for the basic first run with full power EPC.

[3] To the right engineer, the paper may seem obvious. However, having had engineers on the subject area for several years now, modifying the voltage through either variac or SCR hadn't to date been suggested, and I cant understand why not. There may be implications that at the moment I cannot see?

Figure 3 Screen shot of video log of experimentation (From left to right:- Instant Pot (EPC), Nexleaf trekdata logger, Energenie plug monitor, Wemo plug monitor, Variac. Ibutton temperature sensor not shown.

3 Findings

3.1 Soup event (1000W)

Figure 4 shows results from cooking the 2 litres of water normally with the EPC. The chart shows the temperature rising steadily during the heating up phase of the cooking programme, then fluctuating moderately as the power cycles on and off during the cooking phase of the programme. The time to closure of the spigot valve is 12 minutes (from 42 degrees). 'Total cooking time' was 44 minutes.

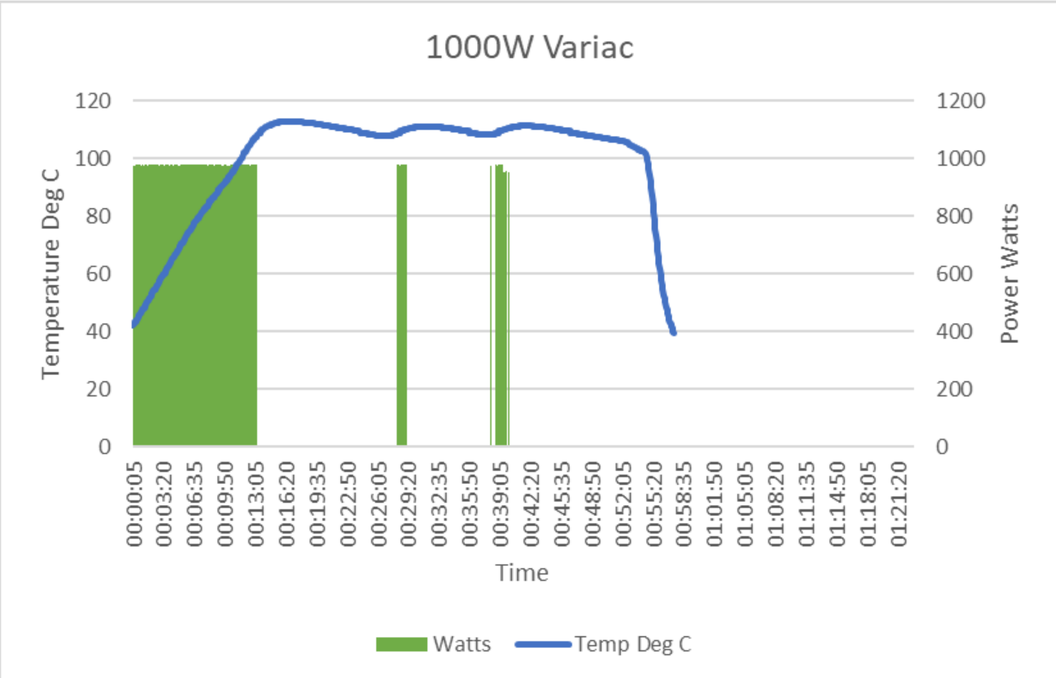

Figure 4 Temperature and power profiles – Instant Pot running at 1000W

Total energy used (MJ)	0.9
Total energy usage (kWh)	0.25

This is a baseline for using the EPC as it is intended – on a 240V AC power supply.

3.2 Soup event (600W)

Figure 5 shows results from cooking the 2 litres of water normally with the EPC but using the variac to reduce the voltage to '600W'. The time to closure of the spigot valve is extended to 19 minutes. 'Total cooking time' was 53 minutes.

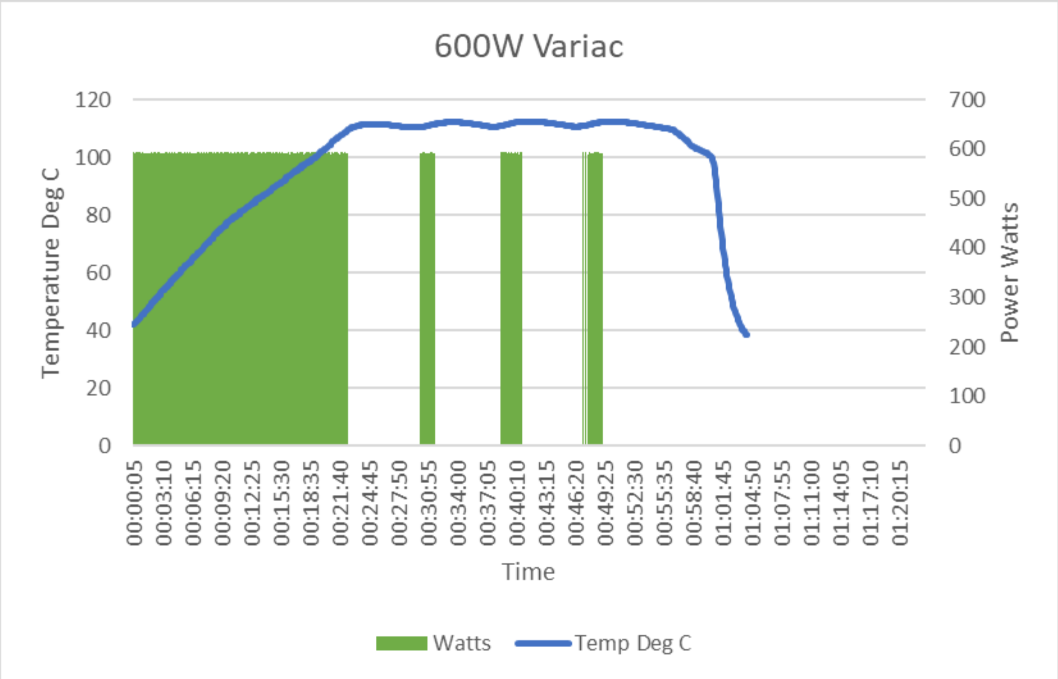

Figure 5 Temperature and power profiles – Instant Pot running at 600W

Total energy used (MJ)	1.008
Total energy usage (kWh)	0.28

The points of note are

- The EPC seems to be working as designed even at the lower AC voltage.
- The total energy is more, presumably because during the heat up phase, the longer time allows more losses?

3.3 Soup event (400W)

Figure 6 shows results from cooking the 2 litres of water normally with the EPC but using the variac to reduce the voltage to approximately 400 Watts. The time to closure of the spigot valve is extended to 28 minutes. 'Total cooking time' was 63 minutes.

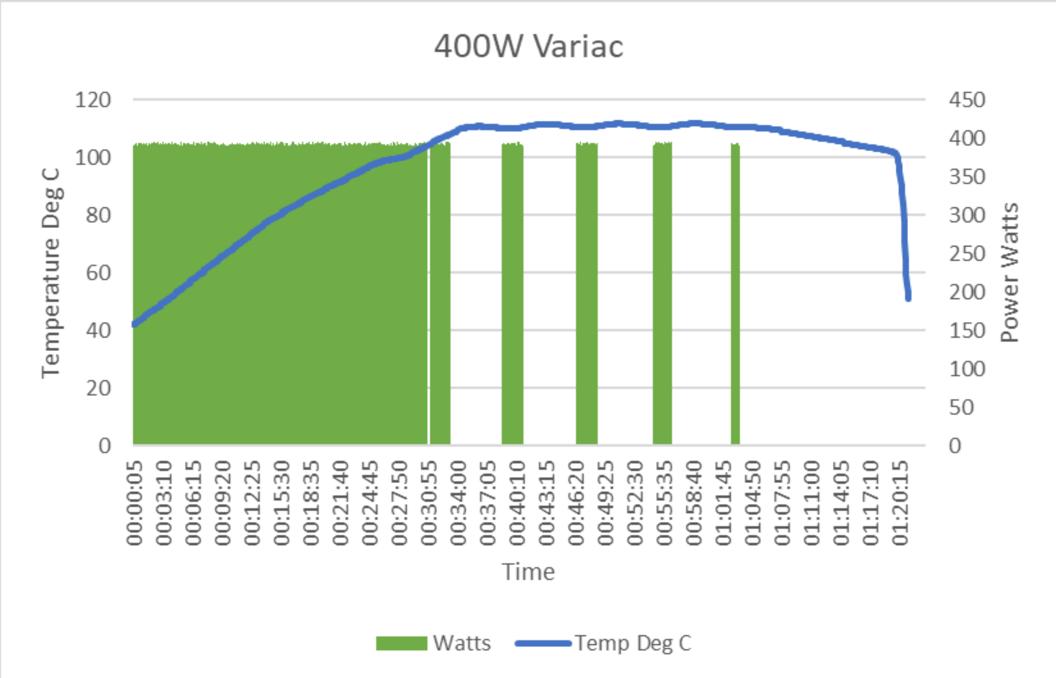

Figure 6 Temperature and power profiles – Instant Pot running at 400W

Total energy used (MJ)	1.152
Total energy usage (kWh)	0.26

Under these conditions, the spigot is struggling to close. Further experimentation suggests that somewhere around 400W is the point at which energy input balances losses associated with steam escape and surface losses from this Instant Pot . Whether the spigot closes or not seems to depend on whether a little bit of water around the spigot 'holds it' and it variously shuts and doesn't shut. The input of 400W is balanced with losses such that the flow of steam is inadequate to **definitely** shut the spigot. At 450W the spigot seems to always shuts but I recommend 500W to be on the cautious side.

Figure 7 Photo of the 'spigot' on the EPC

The 400W uncertainty could be addressed by either changing the weight of the spigot, reducing the flow area around the spigot or starting the whole process with the spigot shut by a mechanical lift. The role of the spigot is to ensure the lid cannot be taken off while the device is under pressure, so it would be important that if the spigot was lifted at the start of the process, that it could NOT be mechanically forced down at the end of the cooking process and still rely on its own weight and there not being any pressure to fall back down. It would still need to fall back into place allowing the lid to open only when the pressure has been released.

Given that these experiments are considering the use of commercial devices (with all their safety features) **unmodified** but used at lower power, even modifying the spigot is perhaps not desirable. Therefore perhaps the conclusion is that appliances should not be used at less than 500W. At 500W the spigot will always shut.

3.4 Energy vs time to cook

While there is some variance in time and energy consumption during the cooking process across the experiments, in general terms it seems that cooking at 1000W raises the temperature of 2 litres water from 42 to 100°C in 12 minutes

Power applied	Minutes to 100 degrees	Minutes to timer start	Minutes to 'Total cooking'
1000W	11:35	13:10	44
600W	19:10	22:25	53
400W	28:15	33:15	63

The unit is raising the temperature of the water to boiling, passing steam through the spigot, which then shuts allowing the pressure and temperature to rise further. Once pressurised, the temperature rises to variously 110.5°C and 111.5°C and the timer kicks in an switches the power off. The power kicks back in when the temperature (and pressure) has dropped.

It does take 20 minutes longer to cook (a 30 minute timed soup) with 400 W than with the original 1000 W, however it is important to note that for longer cooking meals, the timed pressurised phase is the same for all power ratings, it is the bringing to boil and pressurising phase that takes longer. Therefore a 4 hour cook of something like beans would only take 4 hours and twenty minutes, not 5 hours or more.

Given that this contrasts with lighting a wood or charcoal fire, followed by the cooking time and the clear up, the extra 20 minutes from a lower power EPC are unlikely to be noticed by a householder who has made the switch. The effect can be managed by managing expectations.

The one exception is below the 500W mark. As discussed in Section 3.3, it is possible that 400W is not enough to close the safety spigot. At 400W it needs a brief manual intervention. Modification to the spigot could overcome this, by either early shutting, or by reducing the spigot weight.

4 Beyond the variac?

The above exploration of applying lower voltage and therefore lower power to a commercially available EPC used a Variac to lower the voltage. The variac is relatively expensive. "*Variacs can best be described as tapped inductors*"[4]. "*Variacs are designed for a specific input voltage and frequency, and will not work well with other inputs. Only the output is intended to be variable. Variacs also have an output current rating which should not be exceeded.*" "*Variac transformers will be transformers that can put out* ***contrasting measures of voltage*** *from a similar info voltage.*" [5] (my emphasis). The one being used in these experiments retails on Amazon at around £179 (UK price) and therefore its use would double or even triple the price of the appliance.

[4] https://www.nmr.mgh.harvard.edu/~reese/VariacPage/index.html
[5] https://medium.com/@apexelectricals12/how-does-a-variac-transformer-work-a-complete-guide-on-variac-transformer-working-1d2ce43ed304

Figure 8 Screen shot of Variac offered on Amazon UK Accessed April 2020

There is one available on Amazon at $67, which describes itself as a voltage regulator with boost and buck capabilities? – but is not available in the UK, and I am not sure if it works in exactly the same way? (Is this an autotransformer[6] – it looks like one) At the time of writing, this has not been tried, but at this price point, such a device would only double the cost of the appliance.

System cost – it should perhaps be noted that if this device were part of a Solar Home System for instance, which has a capex at around $700 (2020) then an 'extra' $100 is perhaps a significant extra cost but not one that would change the affordability of the whole system to certain segments of the market.

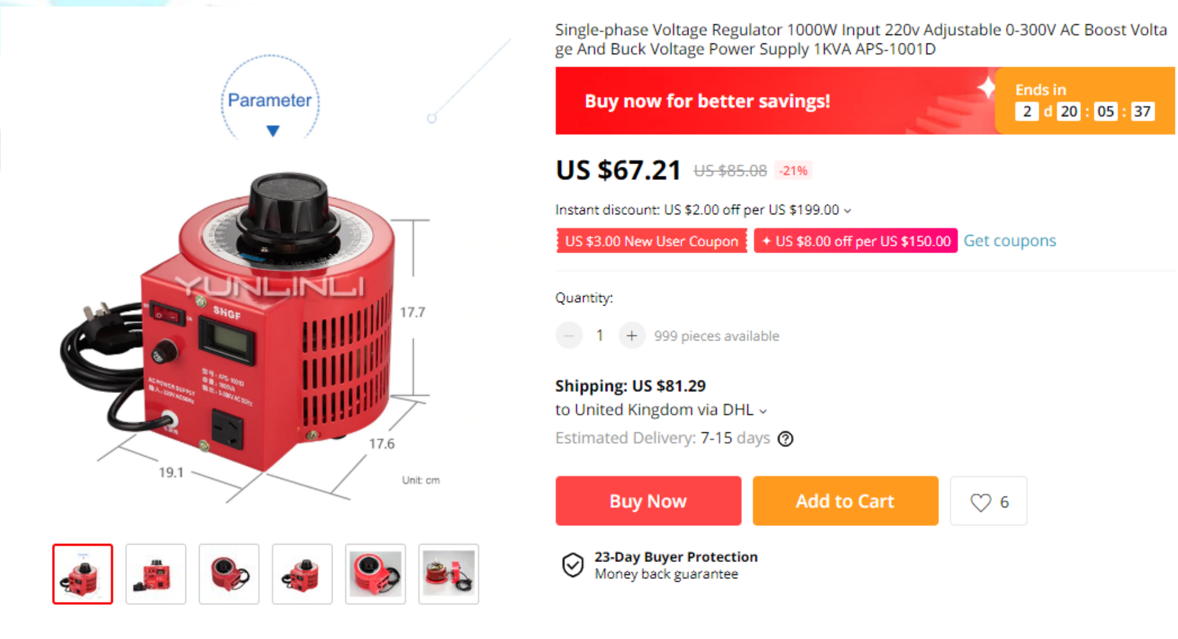

Figure 9 Screen shot of Variac offered Amazon UK (Accessed April 2020)

[6] https://en.wikipedia.org/wiki/Autotransformer

However, if the cost of the voltage regulator could be reduced, that would be valuable.

There is also the possibility of inverting to a different voltage. 24V to 160V and 24V to 180V are both available for the DIY enthusiast on Amazon. At the time of writing this version of the paper these have not been tried.

4.1 Silicon controlled rectifier (SCR) 'voltage regulator'

There is for sale a voltage regulator device which is not as bulky as the variac, is much cheaper and seems to use a silicon controlled rectifier (SCR). We believe there are two types of AC voltage regulator:

- On and off
- Phase control

We purchased two devices that were advertised as 'SCR'. We think these use silicon controlled rectifiers to regulate voltage through phase angle control[7] [8]. SCR is another name for a special type of thyristor[9]. Rather than switching on/off several times within the input AC waveform, they switch on after a controlled time period into the cycle (the phase angle). [We will test these to confirm this at a later date]

Such devices are common on Amazon and two were acquired for experimentation. At £20 (Figure XX) this has a PC fan to keep it cool. Ones that don't have the fan are lower in price, and a very simple version (Figure XX) is sold at £5 (retail, UK). This would imply that such devices could be bulk purchased at almost $2 or less.

Figure 10 Screen shot of SCR voltage regulator offered Amazon UK (Accessed April 2020)

[7] https://en.wikipedia.org/wiki/Voltage_controller
[8] https://www.pantechsolutions.net/single-phase-ac-voltage-controller-of-scr
[9] http://educypedia.karadimov.info/library/an1003.pdf

Figure 11 Screen shot of SCR voltage regulator offered Amazon UK (Accessed April 2020)

[Note, both devices can be adjusted to give a lower power, and the dial (which I believe is a variable resistor?) is very sensitive. I would envisage a bespoke device being made that provided a fixed reduction in voltage (ie with a fixed resistor) such that the consumer could not accidently change it upward.]

1.1 Soup event grid with SCR2 (600W)

The experiment was to see if the £5 SCR voltage regulator (SCR2), could do the same work as the Variac, and would the appliance behave differently. Figure 12 shows results from cooking the 2 litres of water normally with the EPC but using the SCR2 to reduce the voltage to '600W'. The time to closure of the spigot valve was 22 minutes while 'Total cooking time' was 53 minutes.

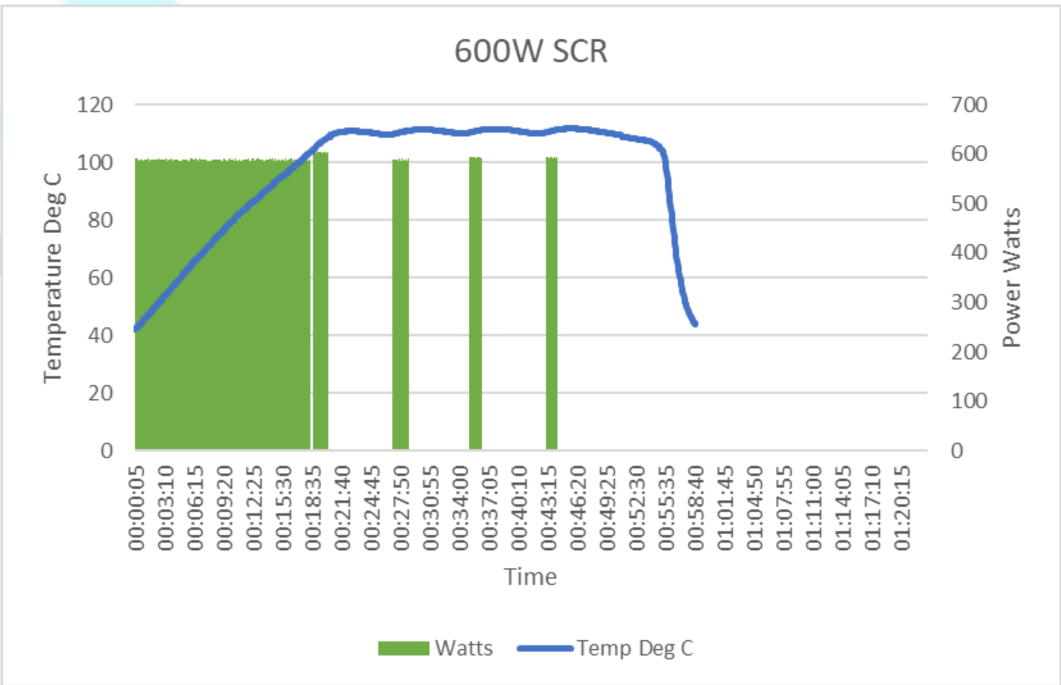

Figure 12 Temperature and power profiles – Instant Pot running at 600W using an SCR modifying the mains supply.

1.2 Soup event grid with SCR2 (400W)

Figure 13 shows results from cooking the 2 litres of water normally with the EPC but using the SCR2 to reduce the voltage to '600W'. The time to closure of the spigot valve was 33 minutes while 'Total cooking time' was 68 minutes.

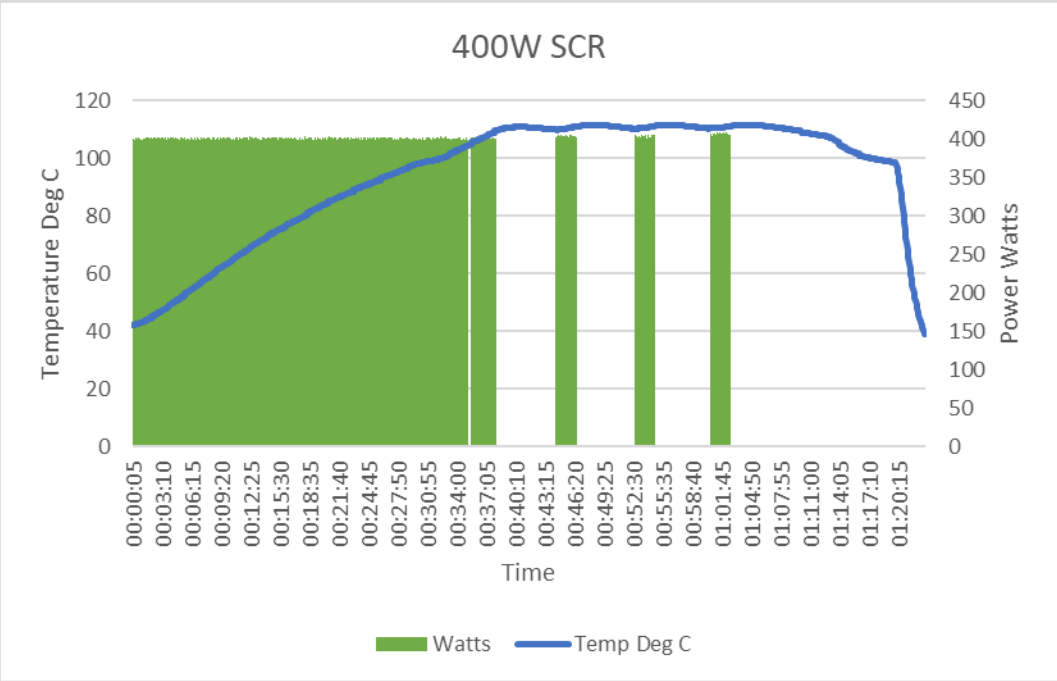

Figure 13 Temperature and power profiles – Instant Pot running at 400W using an SCR modifying the mains supply.

Similar profiles were obtained when using the fan cooled SCR voltage regulator (SCR1). Results are not shown but available.

5 Working with a battery and inverter.

As discussed in the introduction, one mitigation of weak grids, and within the off-grid markets, is to introduce energy storage in the form of batteries. For this exploration of the use of a commercially available EPC, the question was whether a SCR voltage regulator would work with an inverter.

There is discussion that since the SCR works by cutting the phase of the sine wave as described in the links above, there was speculation that they would not work with inverters. The theory suggested was that since 'cheap' inverters produce a blocky slightly square wave that the SCR might not work.

The practical approach was just to try it.

1.3 Soup event on 24V Battery with 'cheap' inverter with SCR2 (400W)

The inverter being used in this experiment is given in Figure 12

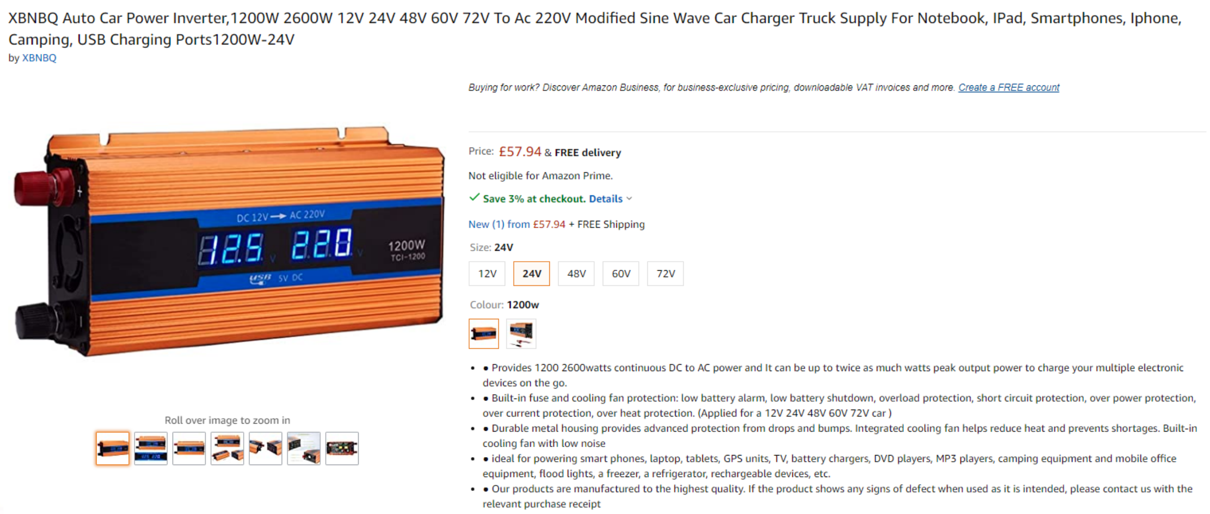

Figure 14 Screen shot of 'cheap' inverter offered Amazon UK (Accessed April 2020)

2 12v Lithium Iron Phosphate Batteries' in series gave the 24V DC.

Figure 15shows results from cooking the 2 litres of water normally with the EPC but using the SCR2 to reduce the voltage to '400W'. The time to closure of the spigot valve was 25 minutes while 'Total cooking time' was 64 minutes.

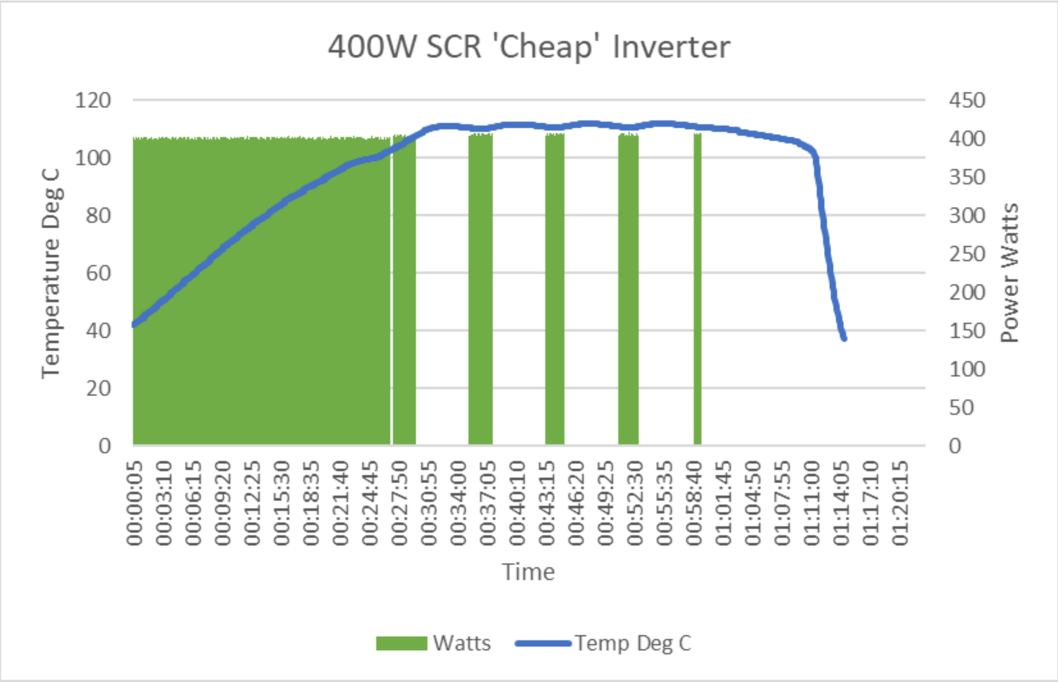

Figure 15 Temperature and power profiles – Instant Pot running at 400W using an SCR modifying the supply from 24V battery and inverter.

1.4 Soup event on 12V Battery with 'pure sine wave' inverter with SCR2 (560W)

The inverter being used in this experiment is given in Figure XX

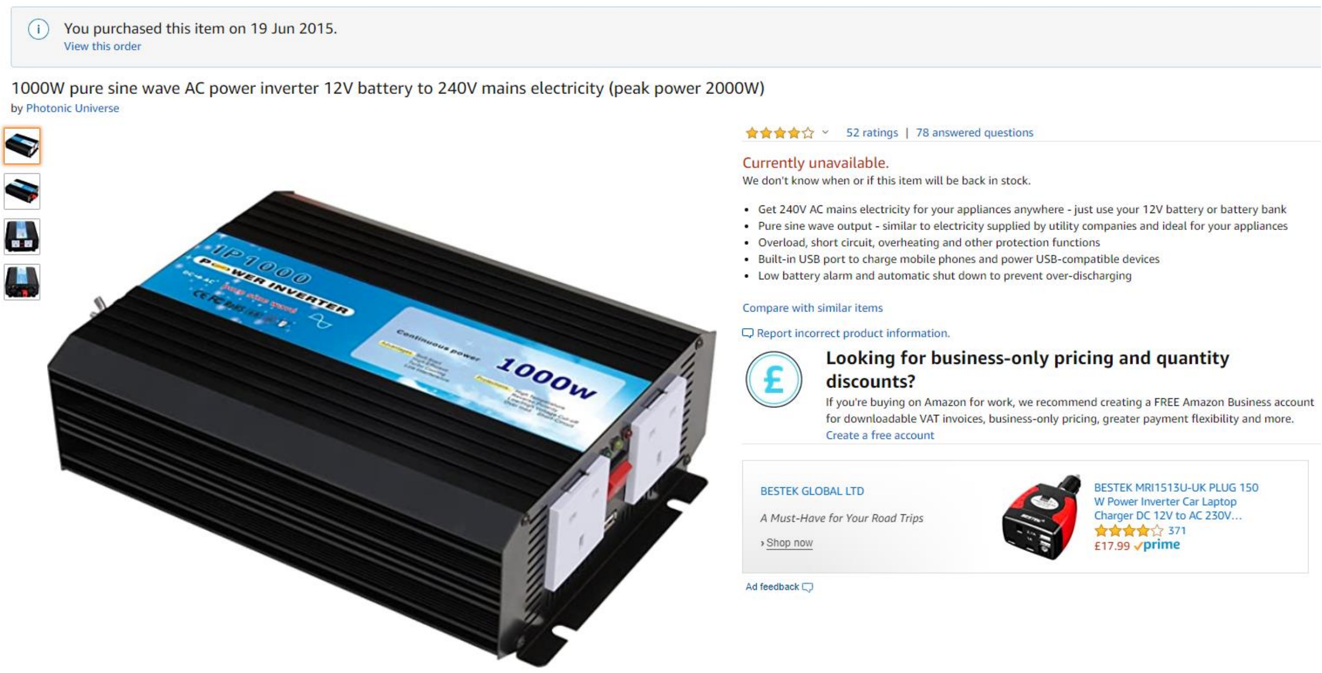

Figure 16 Screen shot of pure sine wave inverter offered Amazon UK (Screen shot accessed April 2020, but purchased 2015)

DC voltage input was supplied by a single 12v 100Ah Lithium Iron Phosphate Battery.

It should be noted that the SCR2 could not be set to 400 W. It jumped between 360W and 560W with minimal movement of the dial (resistor). We believe this may be something to do with changes in sensitivity at different phase angles. While we might expect such an effect from the 'cheap' potentially square/blocky wave, this was a surprise to us that it happened on the pure sine wave inverter. We will examine this further, but since this paper was about the concept of 'voltage regulation' and appliance performance we will return to that in a later set of experiments.

Figure 17 shows results from cooking the 2 litres of water normally with the EPC but using the SCR2 to reduce the voltage to '560W'. The time to closure of the spigot valve was 19 minutes while 'Total cooking time' was 53 minutes.

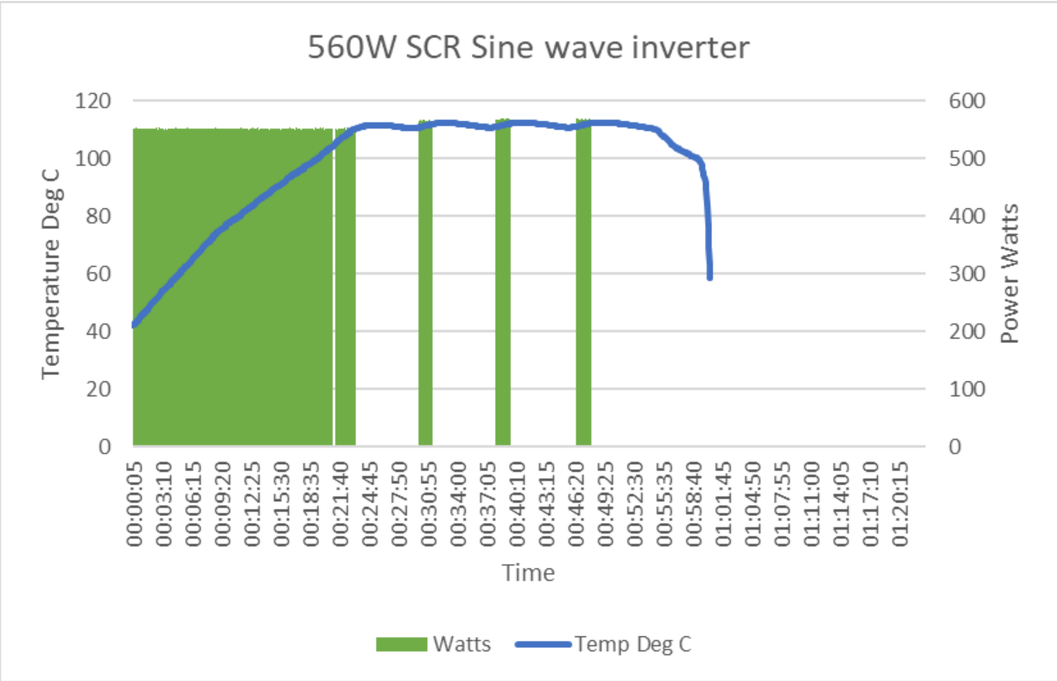

Figure 17 Temperature and power profiles – Instant Pot running at 560W using an SCR modifying the supply from 12V battery and inverter.

5.1 Comparison of appliance performance.

There is effectively no difference in terms of heating the 'soup' between the Variac on the mains and the SCR2 either on the mains or on an inverter. There are some slight temperature variations, but the same variance occurs each time the appliance is driven. Given that the power measurements were plus or minus a few watts, we consider the SCR2 a viable device for reducing the power in an EPC appliance – in the short term – see discussion.

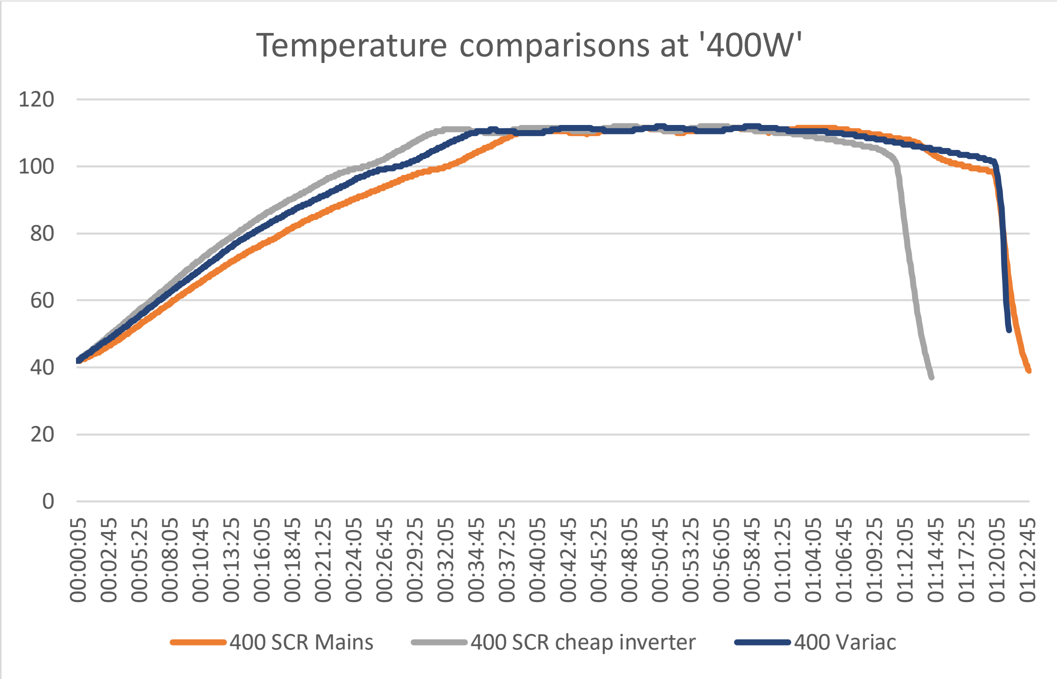

Figure 18 Temperature profiles – Instant Pot running at 400W through various devices

6 Discussion

Since the EPC heating element is a resistive one, it seems possible to lower the power consumption by regulating the voltage. This operates the appliance at lower power with all the safety features of a commercial standardised product.

The Variac is a well-known device and would seem to offer a solution. However, at £200 it seems too expensive for (mini) scaled use (100 households and above?). IF the £63 variac works on the normal principles, then perhaps that is an option.

The SCR is within an good price range, and experiments to date suggest they make the EPC behave as a low power appliance. However, these preliminary experiments do not answer important questions:-

Does the use of the SCR2 compromise the efficacy of the thermal cut outs and digital control features of the appliance? Our understanding is that the thermal cutouts are a combination of mechanical and digital processes. The mechanical processes should not be disrupted by the SCR and while we assume that the digital processes are operating at a rectified low voltage (5V DC?) we have not tested to see if they area affected.

Does the SCR work with all inverters? The reaction of the SCR to the pure sine wave inverter is not what we expected. We thought if anything such a sensitive shift in power would occur in the cheaper inverter. We will conduct further work to understand what is happening – or another researcher is welcome to try a combination of inverters and SCRs to explore this further. Please send us your conclusions.

What is the effect of the SCR on the battery chemistry? The current is being controlled in miliseconds, pulsing between being on an off. Does this intermittent high current draw reduce the life of the battery significantly, and could smoothing capacitors between the inverter and the battery mitigate this?

Is the SCR significantly affected by ambient temperature? Our systems are potentially working in hot climates. Many devices can overheat and this is a concern for energy storage. SCR1 dissipates heat via a (PC) fan (although it may be important to note that the heat is minimal (3 degrees measured), however SCR2 uses an heat sink to dissipate heat and that rises to 55 degrees by end of cooking. If this is working ina hot environment will its components have a lower lifetime.

What is the lifetime of the SCR? Like all appliances and devices, we are unsure of the full lifetime of the product. There is no reason to believe that the SCR will fail any sooner than most PCB circuits, but this has not been tested and will need to be assessed as part of any route to scale.

There is also the option to invert to a lower voltage. This has not yet been explored.

This document has been made to communicate the basic concept and share with our research partners the possibility that while we work towards lower power EPC appliances with the manufacturers, there may be ways we can pilot and prototype safe systems by using SCR voltage regulators.