IMPLEMENTING A LOW VOLTAGE DC NANO GRID FOR A SELF SUSTAINABLE TUKTUK

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ABSTRACT

As the world's energy consumption is changing, the trend to be more self-sustainable is growing. The application of solar panels and batteries for storing energy is becoming a trend for larger mobile systems. While most sustainable energy sources produce Direct Current and most of the appliances require a DC voltage, implementing a DC nano grid would make sense. Not only as an efficient system with better control of the energy and fewer losses but also to be able to use energy as in an off-grid solution. This paper discusses all the electrical parts required for a DC nano grid that will be implemented in a self-sustainable Tuktuk. This small vehicle from ATAG Benelux has a build-in kitchen, induction hob, fridge, and LED lights, as a demonstrator for renewable energy. The electrical system has batteries and solar panels to be fully self-sustaining and an electrical hub motor implementation is considered. Solar panels will cover as much as possible surface area on top of the Tuktuk, with the option to add external solar panels and include a maximum power point tracker. The battery type and its capacity are based on experimental data from cooking tests on a custom-made ATAG DC induction hob. To power, the DC induction hob with 350VDC, a Dual Active Bridge (DAB) is considered. As a backup feature, an inverter is included to power traditional AC induction hobs. Considering the Tuk-tuk as a kitchen but also as an electrical vehicle, it needs to meet the safety requirements for both applications. The full system requirements for this off-grid DC nano grid are all simulated and assembled using in-house developed power electronics and commercially available products. Commercially available products are used to meet the regulations and safety requirements to be able to implement an operational self-sustaining Tuktuk that can be used as a demonstrator. As the electric wheel hub motor is powered from the same batteries it finally transforms the Tuktuk into a clean solar-powered electric vehicle. This will make the Tuktuk independent of fossil fuels and thus fully self-sustainable.

KEYWORDS

DC Nano Grid, Power Electronics, Self-Sustainable, Energy Distribution, Simulation

INTRODUCTION

This paper will explain how a Tuktuk, used as a food truck cooking demonstrator, is rebuilt into a self-sustainable Tuktuk. This vehicle has been upgraded with a kitchen with a gas burner to demonstrate the traditional cooking experience of ATAG[1]. With the demand for traditional gas burners decreasing, the market is shifting to induction cooking, DC-LAB and ATAG joined forces to research the possibility of a fully self-sustainable Tuktuk. To take advantage of the renewable energy sources, a DC micro grid will be implemented. This will give better control of energy and fewer losses as a system, but also makes it an off-grid solution.

The Tuktuk model from ATAG is shown in Figure 1. There are many reports on the electrification of Tuktuks, but they mainly focus only on the drive train of the Tuktuk [2]. Solar-powered vehicles are interesting in the Asian regions, for example in [3] a performance analysis of a solar-powered e-Rickshaw is reported. An onboard battery is charged during the day to increase the driving range compared to only charging during the night. The impact of the drive cycle on the drive train power consumption is reported in [4]. Also in [5], the performance of a 48 volt, 60Ah battery-powered rickshaw is reported. The power consumption for the drive train depends on the aerodynamics of the vehicle [6]. Since the rickshaw is not optimized in respective to the drag coefficient C_W, power consumption at higher speed can be excessive. The induction hob is based on a resonant power supply and is well described in the literature [7][8] The Dual Active Bridge [DAB] required to boost the battery voltage level of 48 volt towards 350 volt was first described in [9] and [10]. All of the techniques used in this Tuktuk are firstly simulated, build, and programmed with an educational power electronics tool [11] and finalized with commercially available products.

The Universal Four Leg [11], the educational tool, is used in all of the practical implementations. The sections in this paper explain how the Tuk-Tuk from ATAG has been upgraded from a natural gas- operated food truck towards a DC full electric kitchen with all the conveniences like an inductive cooking hub, lights, wall sockets, and a refrigerator. Furthermore, the Tuk-Tuk has been made self-sustainable by adding solar panels and internal storage in lead-acid batteries. Each component is described and where applicable, simulation results of the prototyping of the component are given.

Fig. 1: Concept of the self-sustainable Tuktuk.

The used voltage levels applied inside the vehicle are explained in section II. In section III the implementation and simulations of the DC nano grid are described. In Section IV the solar panels and the maximum power tracker are explained. Section V shows the batteries used for storing the power from the solar panels. The DC/DC converter for boosting the 48v DC grid to a 350v DC grid is shown in Section VI. Followed by the DC induction hob in Section VII. Protection against earth leakage is discussed in section VIII where an isolation monitoring device is used. The Electrification of the drive train by adding a brushless DC wheel hub motor with inverter and control is explained in Section IX. The final results are shown in Section X.

DC GRID VOLTAGE AND CURRENT LEVELS

For the implementation of a DC-nano grid, we need to take a look at this system as a decentralized power system. One Tuktuk can represent a household and can both consume and produce energy. In this decentralized power system, energy can be shared over the appliances inside this household. Multiple households can act as a DC-microgrid where energy can be regulated between multiple sources making them prosumers [12]. Before connecting all of these prosumers to the same DC bus, we first need to take a look inside the Tuktuk and see what kind of voltage levels are required for each appliance. Following the Dutch practical guidelines, the NPR9090[13], a DC-grid can be dived in different DC-Zones. In Figure 2, an overview of these DC-Zones is given. The Tuktuk is a protected energy source, and therefore not placed in DC-Zone 0. With batteries inside the Tuktuk, there is a possible high short circuit current possible, which makes it a DC-Zone 1 installation. With solar panels including a controlled output, we have a source with a low short-circuit current and therefore also a DC-Zone 2 installation. DC-Zone 3 & 4 are both based on protection and controlled by the semiconductors. The combination of all the appliances and energy sources makes the installation a combined installation of DC-Zone 1,2,3,4.

On the left side in Figure 3 we see where in the Tuktuk we need the power for the appliances and we can divide that into multiple DC voltage levels. And an additional inverter is connected to the AC grid, in case energy needs to be shared with the AC grid or to fast charge the TukTuk if there is a lack of renewable energy.

Fig. 2: DC-Zones as defined in the NPR9090[13].

On the right side in Figure 3 the structure of the DC grid is shown. In color, the different nominal DC voltage levels[14] are displayed. The main DC grid is the 48-volt level (**gold**) where most appliances are connected. From the 48 volt DC grid, a 12 volt grid (**orange**) is created for the auxiliary loads like lighting inside the food truck and the default loads in the Tuk-Tuk like the head, brake, rear, and blinking lights as well as the car radio. Also, a conventional 12volt refrigerator for mobile homes is fed from the 12 volt supply. The 48 volt grid is boosted towards a DC 350 volt (**blue**) level for supplying the inductive cooking hub and an AC 230 Volt/50Hz outlet (**gray**) for connecting AC appliances. The solar panels (**green**) are connected via a boost converter with a maximum power point tracker to the 48 volt grid.

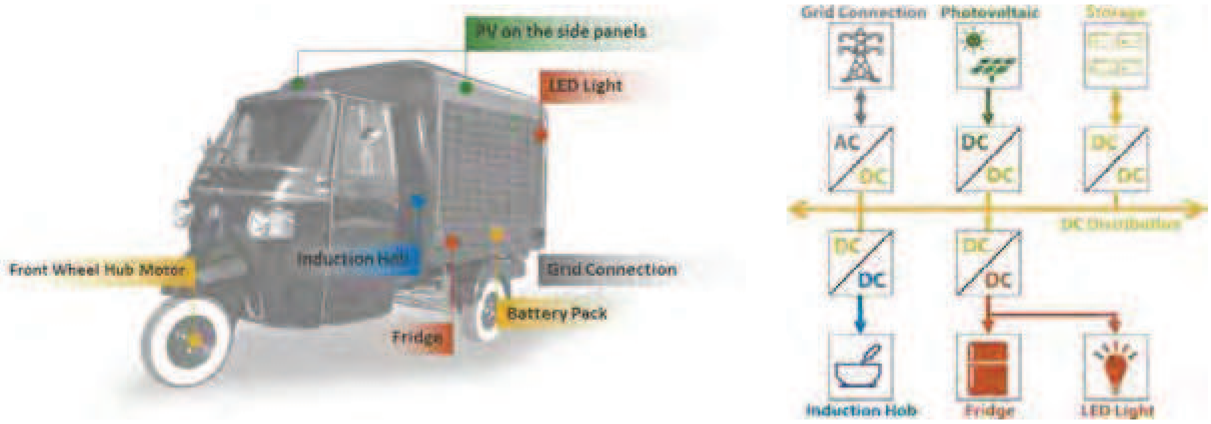

Fig. 3: DC nanogrid implementation Tuktuk divided in voltage levels for the appliances.

SIMULATING AND IMPLEMENTATION DC NANO GRID

While the DC-Zones are known and defined by now, the technical aspect needs to be discussed to realize a DC microgrid. Besides DC/DC converters to create the right voltage levels, also the application and components needed to be defined. A half-bridge topology is the best controllable and universal topology to use as DC/DC converter. Therefore multiple halve bridge converters with their algorithm can increase (*boost*) voltage levels and decrease (*buck*) voltage levels. With two sources connected to a half-bridge converter, it can even act as a bidirectional buck-boost- converter. Most appliances in the Tuktuk can be recreated or controlled with these DC/DC converters. DC/DC converters control the flow of energy, the Universal Four Leg [U4L][10], is used as an educational power electronics tool to do this. This allows to fully test algorithms, in a practical setup, it is also possible to measure the control signals and plot data like the voltage and current. The setup can be programmed with an Arduino Nano and depending on the code shift between multiple DC voltage levels, to power the appliances depending on their power rating. An U4L shows a practical implementation of a DC nano grid. Before all DC/DC converters get connected to the same DC nano grid, simulation models of the U4L help to get a better understanding. The models are available on CASPOC[15]. On the left side of Figure 4 we see the CASPOC model and on the right side the U4L hardware trainer.

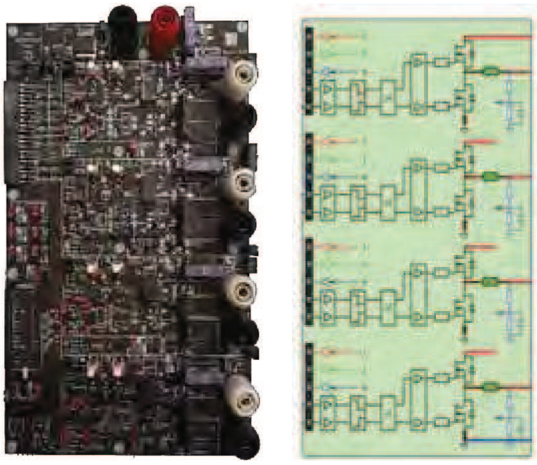

Fig. 4: The Universal Four Leg, simulation model[14] and the educative hardware trainer [10].

SOLAR PANELS AND MAXIMUM POWER POINT TRACKING

To make the Tuktuk self-sustainable, solar panels will be mounted on side of the TukTuk. The TukTuk has two big surface areas where solar panels can be mounted, both of the 'wings' of the TukTuk. These wings can be opened, which will then point directly towards the sky while operational, making it a great place to mount solar panels. An alternative placement for the solar panel is on top of the cabin. This however only has a small surface area. The solar panels will charge a battery that will power the DC appliances (*e.g. induction plate, lights, etc.)* The power output of the solar panels is preferably as high as possible within the dimensions of the TukTuk. The power from a solar panel must be regulated before it can be connected to a battery. To get the best efficiency from the solar panels a charger with an MPPT algorithm is used.

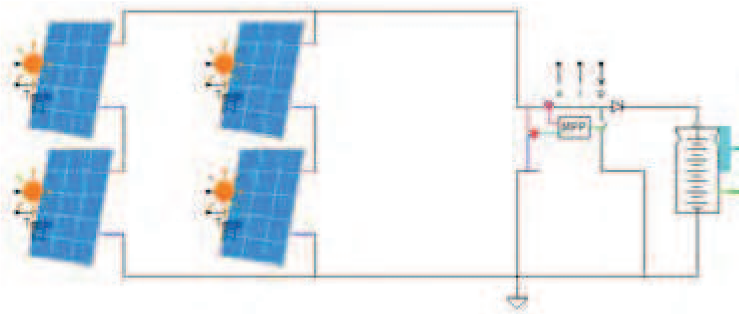

Fig. 5: Simulation of four solar panels with MPPT controller[15].

What is an MPPT algorithm? In layman's terms, the algorithm is to continuously look at how to get the most amount of power by looking for the highest voltage and highest current combinations possible. There are many algorithms to achieve this[16] but the Perturb and Observe (P&O) are implemented. This MPPT algorithm meets the requirements for a slow and easy-to-implement control to code for an Arduino Nano. The power is measured through the halve bridge and the duty cycle is increased or decreased depending on the amount of power through the halve bridge. Every time the output power increases the duty cycle keeps changing to achieve the maximum amount of power possible. This Maximum Power Point Tracking (MPPT) and the algorithm can be seen in Figure 6. A solar simulator Delta power supply connected to the PC is used to see the live feedback of the algorithm able to reach the MPP.

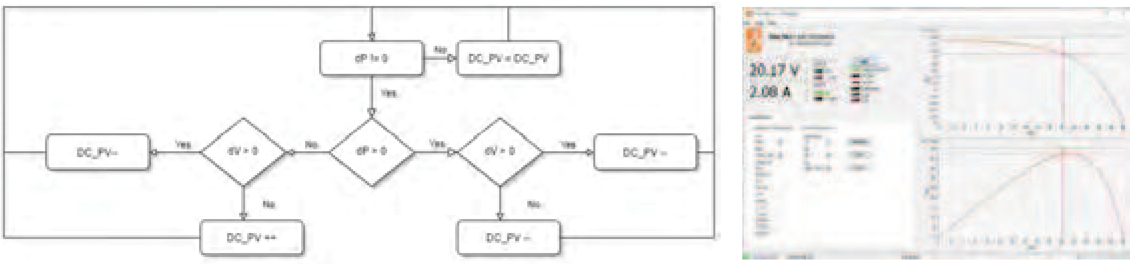

Fig. 6: The MPPT algorithm implemented on a Arduino, PV simulator shows the algorithm reaching the MPP.

Fig. 7 The U4L tested outside compared to a test with a commercially available MPPT.

In Figure 7 we see the MPPT controller works outside in real conditions and has only small deviations from time to time. Compared to a commercially available MPPT controller[17], the self-made version is a bit slower to get to the maximum power point. The deviations are caused by the limited capabilities of the Atmega328p chip on the Arduino. While this proof of concept shows a working principle still the commercially available MPPT is used in the Tuktuk due to the warranty, durability, and robust design to use outdoors.

BATTERIES FOR ENERGY STORAGE

The TukTuk can be showcased everywhere and to be fully off the grid, batteries are needed to store energy. The batteries must be able to power all the devices in the TukTuk and be able to supply power to the high voltage DCDC converter. Batteries come in many different sizes and capabilities, therefore it is important to choose the most suitable for the TukTuk. There are different battery chemistry with their advantages and disadvantages. Currently, the highest density batteries are lithium-based. These are compared to lead-acid-based batteries very light and powerful, but also more expensive and dangerous if handled carelessly. Pricewise and also in combination with the hardware trainer, the lead-acid has the least critical charge algorithm to realize, as there are three states in charging a lead-acid battery. Starting in a constant-current (CC) mode, then constant-voltage (CV) and at last the float charge to compensate for the self-discharge of the battery.

The capacity needed for the Tuktuk is measured on a traditional AC induction hob cooking during a demonstration using power logging tools. During this cooking test, the induction hob is used for almost 5 hours and used 2.64 kWh. This reference is used as a requirement to optimize the simulations models to meet the power consumption of a cooking demonstration.

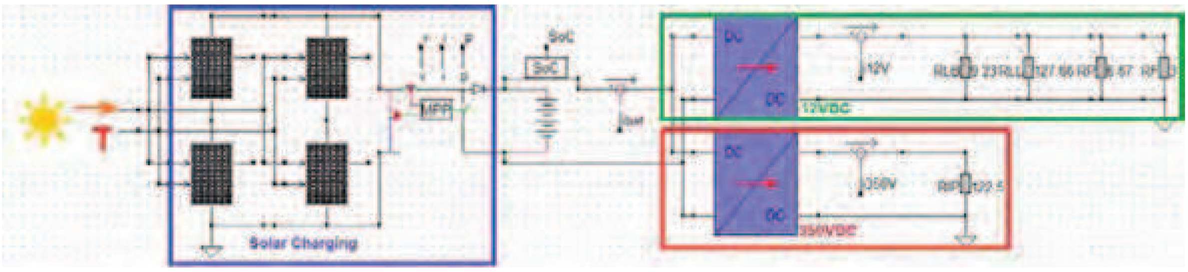

Fig. 8: Solar panels combined with a battery to store the energy.
Appliances (resistive) and DCDC converters as loads to draw energy[15].

The lead-acid batteries are put in series to get the desired 48V, the induction hob needs 1,5kW on a voltage of 350Vdc. To reduce high currents from the battery multiple batteries are placed in series. For this configuration four 12V lead-acid batteries are needed. So for how long will this battery configuration power all the devices of the TukTuk? That depends on the capacity of the batteries. To properly size the batteries the power requirement of the system must be assessed. Since the information of the power use is available, but not always constant, estimation must be done. In the simulation in Figure 8, the solar panels of Figure 5 are connected through an MPPT to the lead-acid batteries. In the simulation model, the capacity of the batteries are specified as the configuration needed for the Tuktuk. Also, two DC/DC converters are connected to the batteries to draw energy from the batteries to represent energy drain during use. All the appliances (*induction hob, fridge, lights, etc*.) in the Tuktuk are powered and represented by a resistive load. This is to see how long the batteries will be able to power the appliances while energy is fed into the batteries by the solar panels.

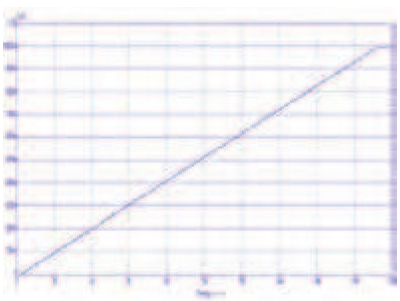

Fig. 9: State of charge during charging

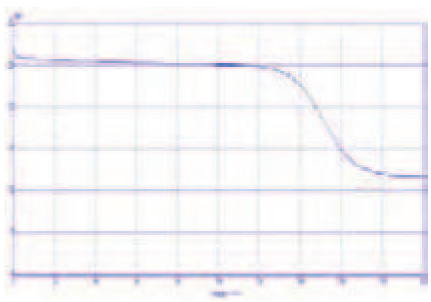

Fig. 10: Discharging the battery with the expected load current

Simulation of charging the battery has been done, the state of charge (SoC) was set to 0% and the components were disconnected from the battery. Figure 9, shows that it takes around 5.5 hours to fully charge the battery. Figure 10, shows the maximum current drawn from the batteries while the resistive loads draw full power from the system. The maximum current drawn from the battery is around 27A while the induction hub draws around 1,5kW from the batteries. These batteries would be able to power the system for at least 3 hours.

To charge these batteries in practice, there are two ways to do this. The first way is by utilizing a charge controller connected to the AC grid to charge the batteries. This can be a great option when the TukTuk needs to be charged fast when there is not enough solar power available. The second, and preferred option, is charging with the MPPT controller of the solar panels. To meet all the safety standards a commercially available inverter is used to charge the batteries, with all algorithms pre-programmed. Also, it has smart functionality to connect to additional modules.

To make sure all appliances have a strong safe connection, a distributor box is utilized, also suitable for high current paths. Also, every appliance has its fuse limited on the expected power that is needed for this appliance. A higher unexpected current will blow the fuse. The distributor box will provide a safe environment when connecting multiple devices with possible bidirectional power flow from unexpected situations. The distributor box is commercially available and also brings information through a Smart Display that is also commercially available. This will show a message on the screen when an error occurs, like a blown fuse, but also battery status, PV power, and load power are displayed.

DCDC CONVERSION

The induction hob uses around 1,5kW and operates at 350V, so the 48V from the battery needs to be boosted with sufficient power. There are different types of DC/DC-boosters, but a Dual Active Boost converter [DAB] is most suited for this application. The topology of the DAB can be seen in Figure 11. The proposed DCDC converter, the DAB, has several advantages, a high power density, it allows bidirectional power flow[19], it is an isolated converter and there are various control methods including implementation of zero-voltage switching. The DAB can also easily be cascading and connected in parallel.

Another advantage is the minimum number of passive components. There are only two capacitors, a high- frequency transformer with an integrated series inductance. This series inductor is the main parameter for the amplitude of the current. Also, soft switching properties can be applied that will allow an increased switching frequency and as a consequence a reduced converter size, especially for the transformer. There is high flexibility when it comes to the optimization of the most important component parameters, being the turns ratio of the transformer, the value of the series inductance and the applied control method. As well as the employed modulation method. Digital control is employed that will allow easy adaption of various modulation methods.

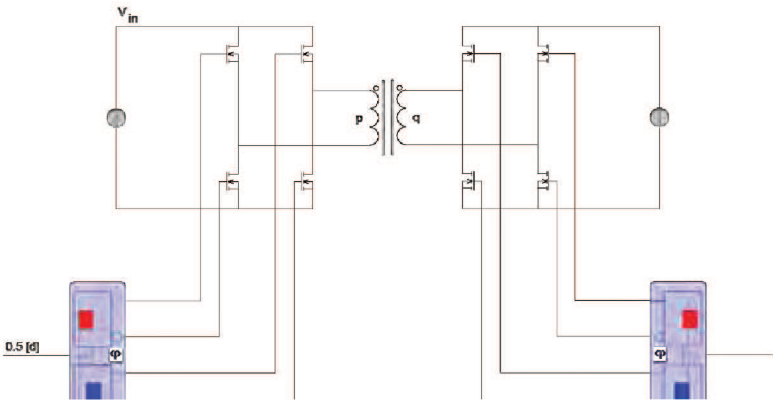

Fig. 11: Topology of an Dual Active Bridge.

Because of these advantages, the DAB is widely used in DC microgrid systems, charging systems for electric vehicles, and energy storage systems and it is therefore applicable for the conversion of the battery voltage of 48 volt to the higher voltage required for the induction hob.

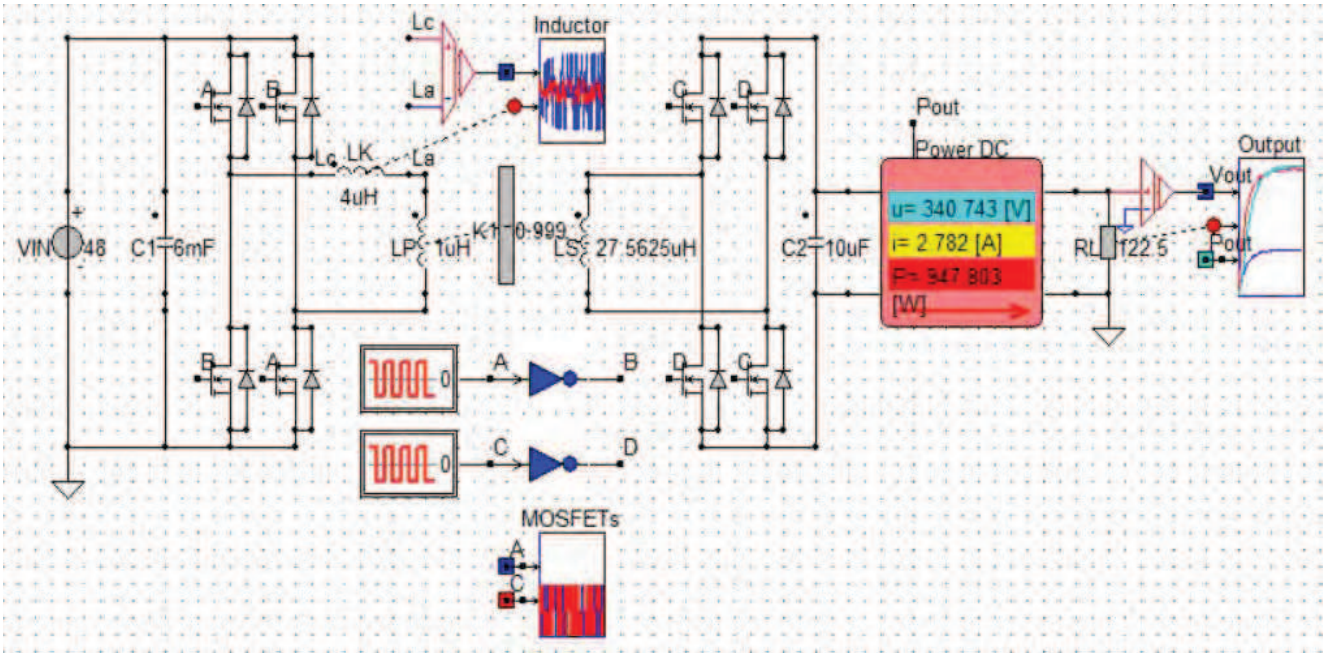

Fig. 12: Simulation of a Dual Active Bridge able to deliver 1kW[14].

A full simulation of the DAB is shown in Figure 12. Here the control algorithm is implemented to transform 48Vdc to 350Vdc. The induction hob is simulated as a resistive load drawing 1kW from the DAB. Finally, the output is measured, to verify if the DAB boost 48V to 350V with 1kW of power drawing from the DCDC converter. The input DC voltage is first inverted to AC by the MOSFET's on the primary side inducing an alternating field in the primary coil The secondary coil can pick up this energy and depending on the phase shift created by the secondary MOSFET's, the energy transferred can be controlled. The response time of the simulated converter can be seen in Figure 13. It takes up to 5ms to build up energy and bring it over to the output terminal of the DAB with a voltage of 350Vdc.

The practical implementation for inside the Tuktuk, is a DAB evaluation board from Infineon[18]. It is a 3300 W 54 V bi-directional phase-shift full-bridge (PSFB) evaluation board. It is capable of boosting the voltage to 350 V and supplying 1 kW. In practice there is a lack of DC induction hobs (*not commercially available*) and an additional commercially available inverter is placed to be able to connect to the AC grid and also be able to provide AC power to traditional AC induction hobs.

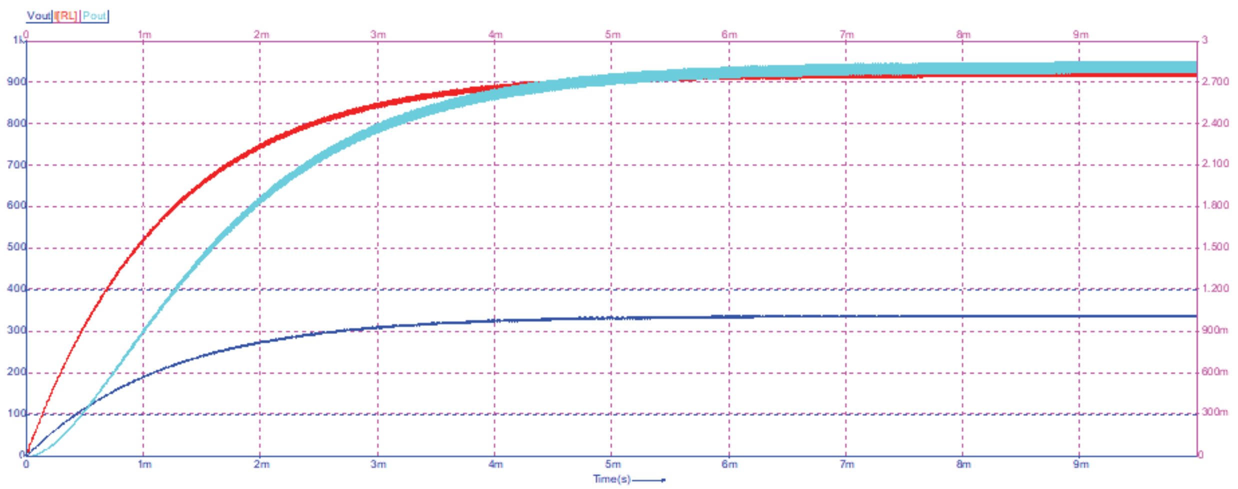

Fig. 13: Simulation graph shows the DAB slowly (5ms) rising to the 350Vdc.
Output voltage(blue, left axis), current (red, right axis) and power (cyan, left axis) in Caspoc

DC INDUCTION HOB

An induction hob is based on a resonant converter. A rectified AC voltage is applied to switching semiconductors and depending on the topology used in the induction hob a switching algorithm is chosen. This high-frequency alternating current through the coil of the induction hob induces a secondary current through the bottom of the pan. The bottom of the pan therefore will heat up. The resonant converter operates from a DC bus voltage and is therefore easily applicable to be converted towards a DC grid[20]. As most traditional AC appliances can handle 230Vac, the rectified voltage already reaches a maximum of 326Vdc. Therefore, depending on the appliance, the step to a 350Vdc is possible with minor modifications.

ATAG is one of the first manufacturers who design prototypes of DC kitchen appliances. Also to be able to provide appliances compatible with renewable energy sources. This 350Vdc prototype, as shown in Figure 14, is installed in the Tuktuk and replaces the old gas burners that were installed in this food truck like Tuktuk. In the side panel, the commercially available smart display is mounted to see the energy consumption. The DC Induction hob is one of the first appliances in this DC prototype line, in addition, a DC oven and DC hood fan are built to have a set of appliances that can smartly manage their energy consumption through DC droop control[21].

Fig. 14: DC-Induction hob inside the Tuktuk.

The high power to be able to demonstrate inductive heating is not suitable to test with a low voltage hardware trainer. Therefore, the DC induction hob is simulated using a single-ended resonant converter. As shown in Figure 15, the duration of the gating pulse of the IGBT controls the amount of power that is transferred inside the pan.

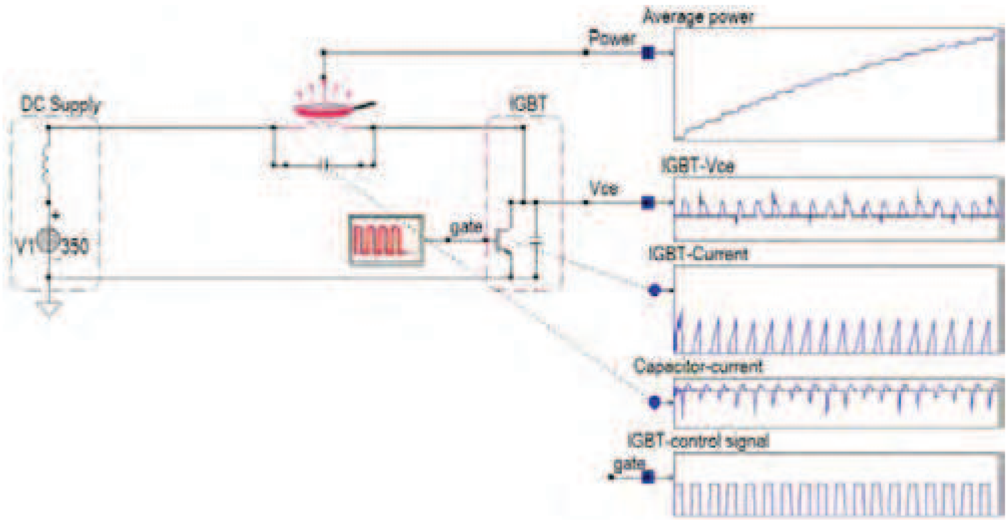

Fig. 15: Inductive cooking using a single-ended resonant converter[20].

PROTECTION

To protect the user against possible dangerous hazards, the first and most simple protection is passive protection. This is inline fuses in-line with all the appliances. And because this system is a floating grid, an Insulation Monitoring Device [IMD] should be added as active protection, it monitors the DC voltage constantly. The IMD is designed to measure the impedance between the line and earth, in this case, the chassis of the Tuktuk. When a low value is measured this may indicate there is a leakage to the protective earth. In this case a DC power relay is switched to entirely turn off the battery. The technique used to detect this kind of earth leakage and the possible switching speed is also simulated in Figure 16. The isoRW425 IMD has kindly been provided by Bender[22] as a commercially available product to use in the Tuktuk. This IMD is an simple and small device, that gives much more safety for use in any kind ofenvironment.

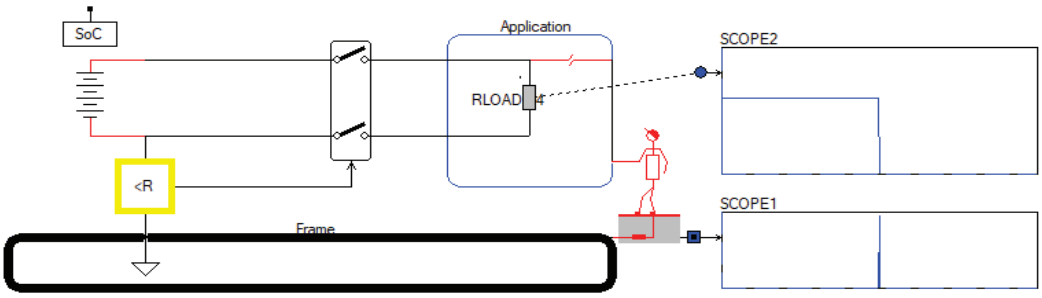

Fig. 16: Simulation of an insulation monitoring device that will switch off when a person leaks current through a ground path[14].

THE ELECTRICAL DRIVE TRAIN

The original Tuktuk is powered by a two-stroke engine for its traction. This is not environment- friendly and not sustainable and renewable. To potentially solve this problem, an electric hub motor is placed as the front wheel, Figure 17 shows the ordered hub motor that has the same size as the front wheel of the Tuktuk. The hub motor is of the type: brushless direct current motor. This type of motor is very common among electrical vehicles. The power for the wheel can come from the 48V battery pack of the Tuktuk and the only thing to drive the wheel is a high-end microcontroller. The specifications of the hub motor are 48Vdc and 2kW. The specifications of the hub motor are very important while choosing a motor driver. The MOSFET's in these controllers must be able to handle the peak current when accelerating from a standstill. Also, the microcontroller, should be able to drive the MOSFET's.

To find out how fast the TukTuk will be able to drive with this specific hub motor, the Tuktuk is simulated as a moving vehicle, as shown in Figure 18. According to the simulation, the TukTuk should be able to reach a maximum speed of 20km/u within 90 seconds under perfect circumstances (*flat road, no wind*). This should be enough for demonstration purposes but will not have enough power to drive on a normal road.

Fig. 17: The used 2kW hub motor.

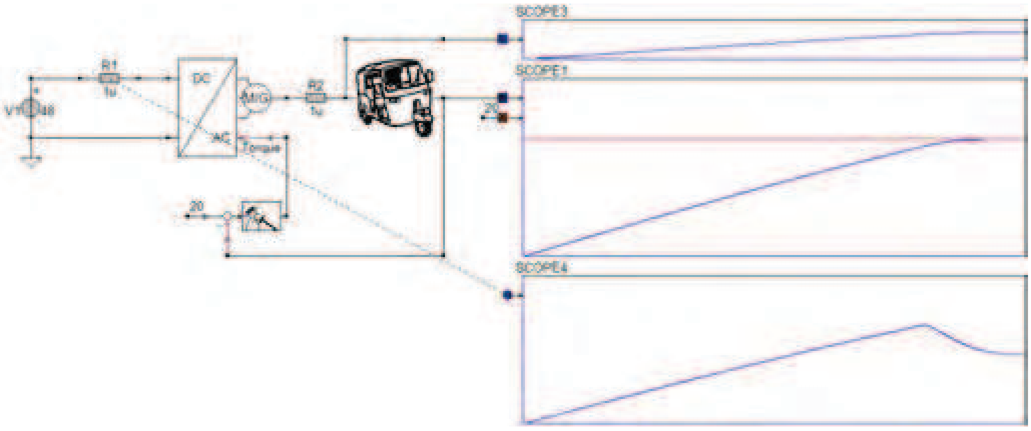

Fig. 18: Simulation of the 2kW hub motor inside a Tuktuk like a vehicle, weight matches the Tuktuk[14].

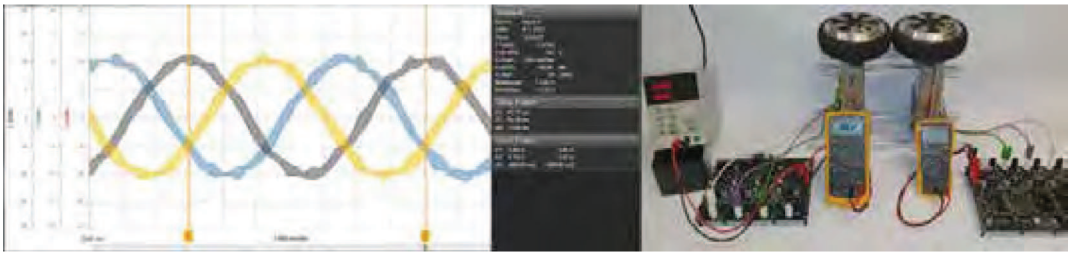

Fig. 19: The measured three-phase output and the practical test setup realized with two U4L boards to drive two motors.

The motor control was first tested with the help of an external motor drive train set up, see figure 19. In this setup two, equally sized motors are mechanically coupled, where one machine acts as a motor while the other machine acts as a generator. The U4L is used to control both machines, where one machine is speed controlled and the generator is simulating the mechanical load and therefore configured as torque controlled. Although the wheel hub motor includes Hall sensors for rotor position detection, a sensorless Field Oriented Control method is applied. The advantage is that only three wires are required to power the motor and the vulnerable sensor wires are not required, reducing the failure rate of the drive train. The inverter is powered from the 48 volt batteries directly and cascaded speed-current control is implemented as a digital control in the C2000 [23].

A first experiment to test the wheel hub motor is shown in fig. 20. The hub motor was mounted underneath the Tuktuk for testing purposes. In this way, the test could be performed in an early stage before the actual replacement of the front wheel by the wheel hub motor. With a small moment of inertia, the used hub motor can get the Tuktuk moving. Therefore this proof of concept is working as expected. A higher power hub motor should be chosen to use the Tuktuk to drive a longer distance. All the components used inside this Tuktuk make it weigh around 500kg, also in simulations, a normal Tuktuk would have a better performance with a 2kW hub motor.

Fig. 20: The hub motor mounted for testing performance under load.

With this last component ready to install in the Tuktuk, the whole Tuktuk is 3D-modeled. In this way, all dimensions are clear and give the possibility to fit all the commercially available components. These components already are available to download and give a good indication of the possibility of placing all of these components. While the hub motor is in front of the chassis the highest weight is on the middle of the back suspension. This was the only possible location to place the batteries and stay balanced as much as possible.

Fig. 21: The 3D modeled Tuktuk with used electronics modeled.

IMPLEMENTATION AND DEMONSTRATION

With all components and converters, 3D modeled the full DC nano grid installation can be implemented in the Tuktuk. The old installation of the Tuktuk contained a gas installation for gas burners, as this Tuktuk is used as a festival food truck. These old gas burners were replaced with DC and AC induction hobs (*to have both options available*). And the gas tank, in Figure 22, is removed. This backplate is then replaced with the DC nano grid and appliances, as described in the previous sections. Figure 23, shows the new installation.

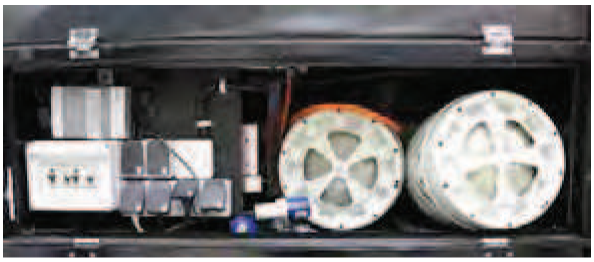

Figure 22: Old gas installation

Figure 23: New DC installation in theTuktuk

After the TukTuk was installed, tests have been carried out to compare the simulations to the real-life results. To make sure the system doesn't run too hot, a thermal imaging camera is used to check the temperatures of the system, cables, and connectors in particular. Wrong installed connections will have a high impedance and therefore will get hot through the high current flowing, Figure 24,25,26.

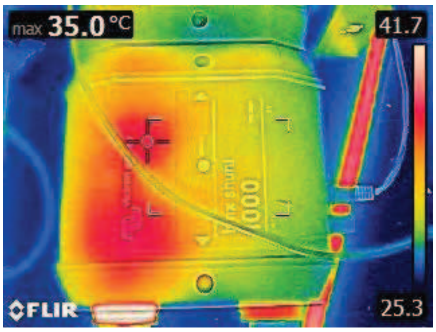

Figure 24: Shunt

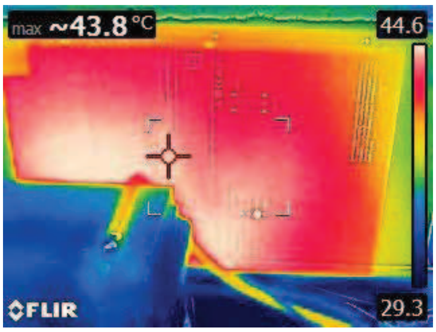

Figure 25: Inverter

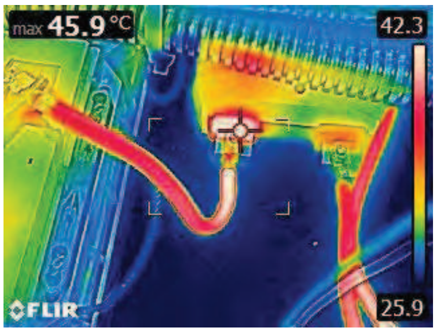

Figure 26: Wires

To test the system the induction hob was used to draw high current through the system. The information of the power draw was provided by the built-in screen of the Tuktuk. A pan of water was used to have a real load on the induction hob. The first test was a 50% power setting on the induction hob. Figure 27 shows the SoC if 1kW is drawn from the system until the batteries are empty, this gave a runtime of around 2 hours. The total runtime of the system was around 45 minutes with a 2kW cooking test, the SoC can be seen in Figure 28. Drawing higher currents from the battery decreases the running time dramatically. The dynamic test, in Figure 29, consists of a real BBQ cooking session with variable power drawn. Since it is not predictable how a chef will use the induction hob, the results will be truly dynamic. The results were better than expected comparing the results to the 1 and 2kW tests.

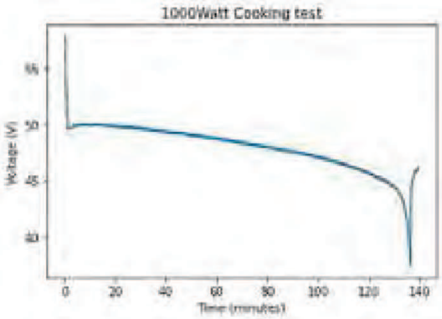

Figure 27: Cooking test 1kW

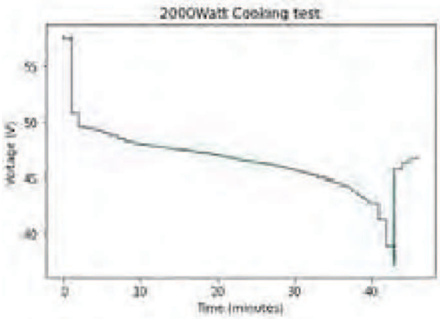

Figure 28 Cooking test 2kW

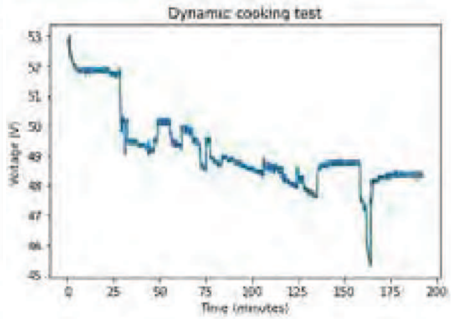

Figure 29: Dynamic cooking test

Figure 30: The Dynamic BBQ cooking session to test the whole Tuktuk system in practice.

The dynamic BBQ test can be seen in Figure 30, with an active power logger connected, supported by Fluke. When the batteries are fully drained by the use of the TukTuk, they can be charged with the help of the inverter. It is very important to know when the batteries are fully charged from fully discharged. Therefore a charge test is also carried out to find out how long it takes to charge the batteries. The plot of the SoC while charging can be seen in Figure 31. Using the TukTuk dynamically gives more cooking time than synthetic test at fixed power. A measurement of the voltage level during a live demonstration of the food truck reveals a 5% voltage drop over 180 minutes of using the inductive cooking hub.

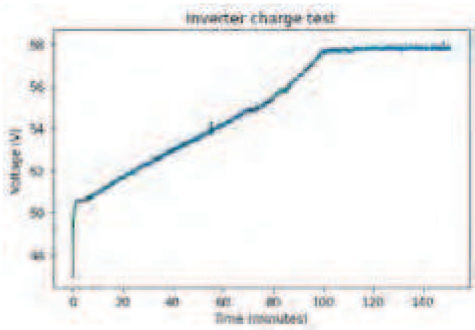

Figure 31: SoC while charing the batteries.

CONCLUSION

In this paper, a newly introduced food truck built inside a Tuk-Tuk is discussed. The complete drive train including the dc grid that is required to control the food truck is designed and implemented in a gasoline-powered food truck, where the gasoline drive train and gas tanks for cooking are removed. The four 12 volt lead-acid batteries in the dc grid supply an inductive cooking hub and the refrigerator, as well as supplying power for the electric drive train. Solar panels on the roof and side of the food truck charge the batteries. An isolation detection is added to ensure safe operation and can detect any short circuit to the chassis of the food truck.

This demonstrator aims to show the minimum requirements for implementing a dc grid to create a self-supplying microgrid. The main battery voltage level is selected as 48volt, from which a lower 12 volt for the auxiliary supplies and a 350 V DC for the induction cooking hub are created. Since the food truck is a mobile vehicle, the type of electric grid is an isolated system, however, the vehicle and the metal frame inside the vehicle are considered as the grounding for the electric system.

The results from the performed simulations to study the overall system behavior, as well as the detailed operation of the various components, agree with the measurement results. Simulations and measurements were performed for the solar maximum power tracker, the working of the DCDC converters, and the simulation of the drive train of the electrified Tuk-Tuk.

The measurements show that using these fully charged batteries, the induction hob, refrigerator, and lighting can operate for at least 45 minutes when using continuously 2kW of power and over 2 hours when using continuously 1kW. The difference originates from the higher overall losses when withdrawing a higher amount of power from the batteries. The demonstration of a dynamic cooking test, being a kind of cooking drive cycle, revealed 180 minutes of using the induction hob is possible. A measurement of the voltage level during a live demonstration of the food truck reveals a 5% voltage drop over 180 minutes of using the inductive cooking hub.

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References

[1] ATAG Benelux, Kitchen appliances and consumer electronics [Online] Available: https://www.atagbenelux.com/

[2] C. Yiangkamolsing, Y. Laoonual, S. Channarong, W. Katikawong, P. Sasawat and B. Yaotanee, “A Development of Electric Tuk Tuk Conversion in Thailand,” 2019 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia- Pacific), 2019, pp. 1-8, doi: 10.1109/ITEC-AP.2019.8903895.

[3] D. Sahu and P. S. R. Nayak, “A Substantial Modelling and Analysis of Solar Powered e-Rickshaw Drive System,” 2021 International Conference on Sustainable Energy and Future Electric Transportation (SEFET), 2021, pp. 1-6, doi: 10.1109/SeFet48154.2021.9375651.

[4] Abu mallouh, Mohammed & Denman, Bradley & Surgenor, Brian & Peppley, Brant. (2009). A Study of Fuel Cell Hybrid Auto Rickshaws Using Realistic Urban Drive Cycles. JJMIE, Jordan Journal of Mechanical and Industrial Engineering, Volume 4, Number 1, Jan. 2010, ISSN 1995-6665, Pages 225 - 229

[5] B. Saha and B. Singh, “Solar PV Integration to E-Rickshaw With Regenerative Braking and Sensorless Control,” 2020 IEEE 17th India Council International Conference (INDICON), 2020, pp. 1-6, doi: 10.1109/INDICON49873.2020.9342184.

[6] Singh, Neha & Singh, Pratyush Kumar & Abbey, Saransh & B T, Kannan. (2020). Some studies on Aerodynamics of Tuk-Tuk Vehicle. AIP Conference Proceedings. 2311. DOI 10.1063/5.0034716.

[7] E. Ceuca and A. Tulbure, “Practical behavior of DC-DC converters in home applications — Induction hob,” 2012 IEEE 18th International Symposium for Design and Technology in Electronic Packaging (SIITME), 2012, pp. 95-98, doi: 10.1109/SIITME.2012.6384354.

[8] Y. Slavova and M. Marinova, “Mathematical Modelling of the Impact of Operational Factors on the Energy Efficiency of an Induction Hob,” 2021 17th Conference on Electrical Machines, Drives and Power Systems (ELMA), 2021, pp. 1-4, doi: 10.1109/ELMA52514.2021.9502994.

[9] De Doncker, R. W., Kheraluwala, M. H., & Divan, D. M., Analysis, design and experimental evaluation of a high power high frequency bidirectional DC/DC converter. In EUROPEAN CONFERENCE ON POWER ELECTRONICS AND APPLICATIONS (EPE-conference Firenze 1991 Vol. 1, pp. 568-568).

[10] W. A. A. De Doncker, D. M. Divan and M. H. Kheraluwala, “A three-phase soft-switched high-power-density DC/DC converter for high-power applications,” in IEEE Transactions on Industry Applications, vol. 27, no. 1, pp. 63-73, Jan.-Feb. 1991, doi: 10.1109/28.67533.

[11] DC-LAB, Educational Hardware Design. [Online] Available: http://www.dc-lab.org/

[12] Y. Parag and B. K. Sovacool, “Electricity market design for the prosumerera,” Nature Energy, vol. 1, no. 4, p. 16032, 2016. [Online]. Available: http://www.nature.com/articles/nenergy201632

[13] NPR9090, Nederlandse Praktijk Richtlijn, Online Available: https://www.nen.nl/en/npr-9090-2018-nl-250370

[14] E. Rodriguez-Diaz, F. Chen, J. C. Vasquez, J. M. Guerrero, R. Burgos, and D. Boroyevich, “Voltage-Level Selection of Future Two-Level LVdc Distribution Grids: A Compromise Between Grid Compatibiliy, Safety, and Efficiency,” IEEE ElectrificationMagazine, vol. 4, no. 2, pp. 20–28, jun 2016.

[15] Simulation Research, Caspoc Simulation and Animation. 2021 [Online] Available: https://www.caspoc.com/

[16] D. Beriber and A. Talha, “MPPT techniques for PV systems,” 4th International Conference on Power Engineering, Energy and Electrical Drives, 2013, pp. 1437-1442, doi: 10.1109/PowerEng.2013.6635826.

[17] Victron Energy Blue Power, [Online] Available: https://www.victronenergy.nl/

[18] Infineon EVAL_3K3W_BIDI_PSFB, Dual Active Bridge Application Note, [Online] Available: https://www.infineon.com/cms/en/product/evaluation-boards/eval_3k3w_bidi_psfb/

[19] P. J. van Duijsen and D. C. Zuidervliet, “Structuring, Controlling and Protecting the DC Grid,” 2020 International Symposium on Electronics and Telecommunications (ISETC), 2020, pp. 1-4, doi: 10.1109/ISETC50328.2020.9301065.

[20] P. van Duijsen, J. Woudstra and D. Zuidervliet, “Requirements on Power Electronics for converting Kitchen Appliances from AC to DC,” 2019 International Conference on the Domestic Use of Energy (DUE), 2019, pp. 190-197.

21. Spaans, Alexander and Zuidervliet, Diëgo and van Duijsen, Peter, Droop Control in DC Grids using the Universal Four Leg as Laboratory Setup (July 26, 2021). AIUE Proceedings of the 2nd Energy and Human Habitat Conference 2021, Available: http://dx.doi.org/10.2139/ssrn.3899714

22. Bender, Insulation Monitoring, Available [Online]: https://www.bender.de/

23. A. Üzel, D. C. Zuidervliet and P. J. v. Duijsen, “Educational Set-up for Brushless Motor Drives,” 2021 17th Conference on Electrical Machines, Drives and Power Systems (ELMA), 2021, pp. 1-6, doi: 10.1109/ELMA52514.2021.9503025.