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Mobile PTO generator for agricultural usage

A developed and constructed power take-off generator is used as a mobile electrical power supply. Such a device drives asynchronous motors in open-loop mode and permanent magnet synchronous motors in sensorless closed-loop mode. Furthermore, it is also possible to apply AC voltage, 3x400 V and 1x230 V, to use external electrical appliances. The possibility for constant DC link voltage independent of the PTO revolutions is also shown.

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Abstract
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Controllability and Efficiency are the most important requirements of agricultural drives. So far power drives have been realized by direct mechanical or hydraulic drives But meanwhile electric drives provide new and suitable properties, like a high power density, speed and torque control and all necessary interfaces. The efficiency is about 80 to 90 percent with a high power density at low weight. Besides the implements already equipped with electronic components the importance of electric power drives in agricultural engineering is expected to rise in future as market research shows [1].

But, until sufficient electrical power is installed on tractors, there is a demand for a mobile electric power supply. [2,3]

Requirements to be fulfilled for a PTO-Generator

A PTO-Generator should be portable with easy installation and easy use. Almost all manufacturer use a three-point hitch and the plug interface proposed as a standard from AEF [4]. The portability of the different products is not given in every case. So not every model can be taken as a generator on field. Also the advantage of a constant DC-link due to an active step-up converter, which makes the whole PTO-generator independent of the PTO revolutions and therefore independent of the engine speed, is not state of the art. Some manufacturers use gear boxes with their electric drives which increases efficiency – high speed electric drives have better efficiency in comparison – but decreases also the all-over-efficiency and inreases maintenance and installation costs. In the following article a PTO-generator designed and build by the University of Technology of Vienna is presented as well as tests with various external devices.

The PTO-generator

The generator unit is a permanent magnet synchronous machine (PMSM) with a nominal torque of 165 Nm at a nominal speed of 1000 rpm with a three time overload capability. It is an outer rotor machine with buried magnets and fractional-slot concentrated windings [5].

The generator is coated by iron sheets and has an interface to the power take off. It is mounted to a three-point hitch and surrounded by a two-inverter power pack on the top, radiator and pump for watercooling on the one side and plugs, choking coil and output mode switching relays on the other side. **Figure 1** shows the whole PTO-generator device in a draft as well as a picture of the power pack itself and mounted on a tractor.

The generator unit provides electrical power with a three phase alternating current depending on the power take off speed. A simple rectifier would result in a variable DC link voltage depending on the induced voltage of the machine. Therefore a active H bridge converter is used to supply a constant DC link voltage. **Figure 2** shows the controller with two input parameters. With the DC link reference value the q-axes current is controlled.

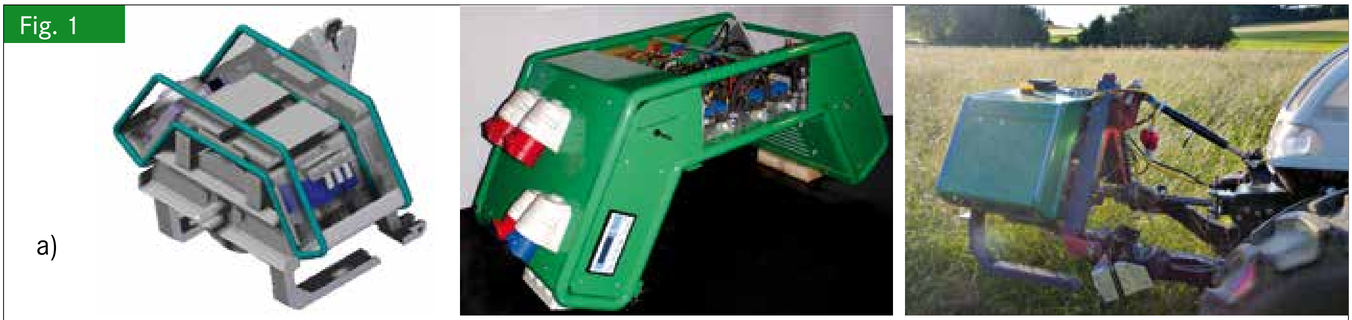
A negative current i_q results in a higher DC link voltage than the induced voltage according to the actual PTO speed. The inverter is driven in an active step up chopper mode. In case the revolution speed respectively the induced voltage is higher than desired, the generator is driven in a field weakening mode. Field weak parameter controls the d-axes current which results in a lower induced voltage – a step down converter.

Besides a constant DC link voltage there are more output modes using a second identical inverter, see **Figure 3**:

- Asynchronous mode: for open-loop ASM
- Synchronous mode: sensorless close-loop PMSM
- Isolated network operation: 3x400 V / 1x230 V with 50 Hz

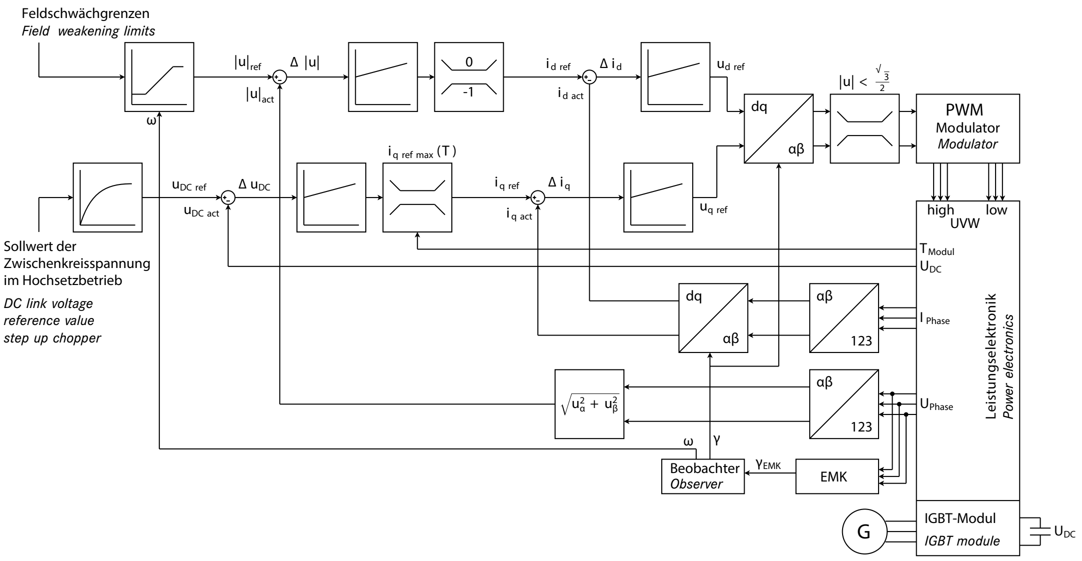
Input and output inverter are the same type. The circuit board of the power part is installed on a aluminum block for water

Fig. 1



3-D draft of the PTO generator (a), *picture of the power pack, half open* (b), *PTO generator in the field* (c)

Fig. 2



DC link voltage controller

Fig. 3

1200V-250A-IGBT water cooled high power inverter

cooling purpose. One can see the DC link condensators (black cylinders), the current sensors (black rings on the upper end) and the voltage sensor (on the right hand side). In the center there is the control for the three power IGBTs (Insulated Gate Bipolar Transistors). Above the power part there is control board with the microprocessor and the interfaces for various in and output signals [6].

The power flow of the PTO-generator is drafted in **Figure 4**. On the left hand side the PTO which drives the generator. The three-phase voltage is active rectified to the DC link in a first inverter working as a active step up converter. The second inverter then converts the voltage according to the currently used ouput mode. In the example an electric drive is powered. For safety reasons there is a braking chopper to limit the maximum DC link voltage. Furthermore an insulation monitor detects possible erros in the electrical system and switches off the power on the input side to protect the environment.

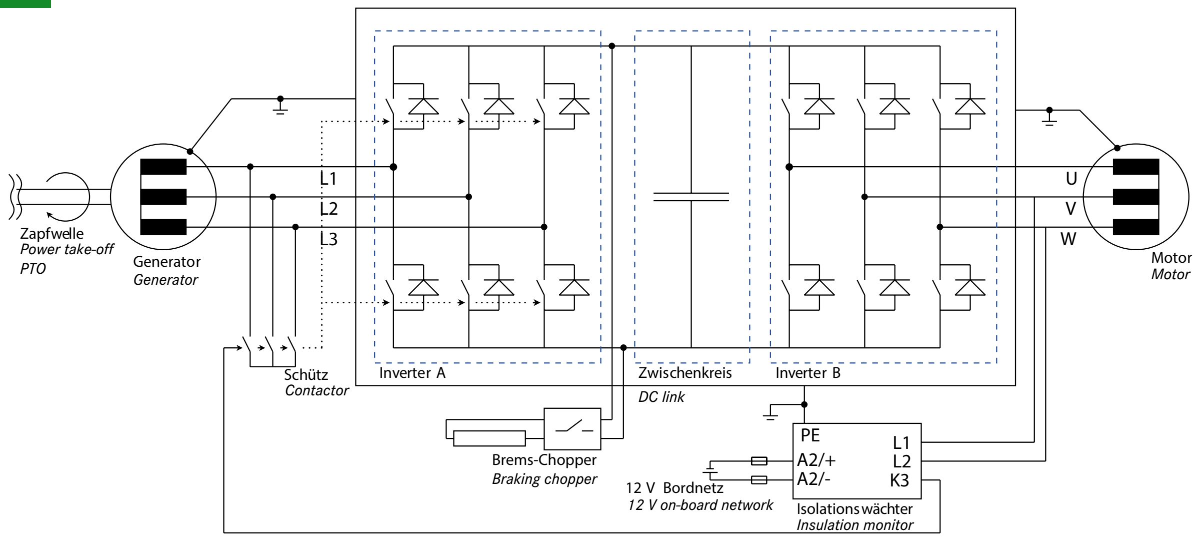
Measurements

The PTO-generator has been tested on the test bench and been used as a power supply on the field.

The PTO-generator was tested on test bench as well as in field. In **Figure 5** (a) measurements of the step up chopper is shown. In the left image, the chopper is activated and the actual DC link voltage (Ch2) follows the smoothed reference value (Ch1). Ch3 shows the needed q-axes current, after some control deviation a small amount sets the DC link voltage to the specified value. Ch4 shows the measured phase current.

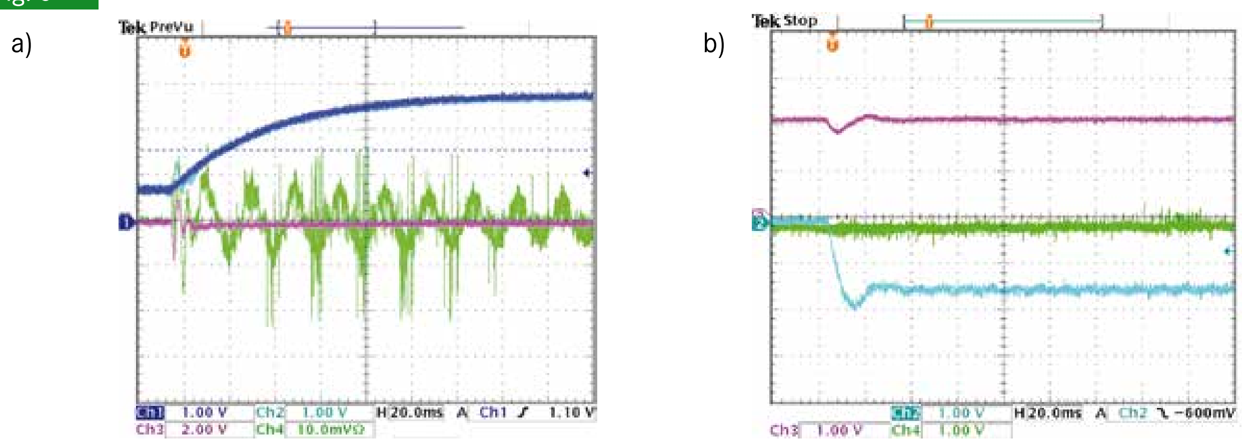
In **Figure 5** (b) the DC link voltage is already at the reference value (Ch3) and a load of about one third of the nominal load is applied. The voltage has a slight breakdown, and the

Fig. 4



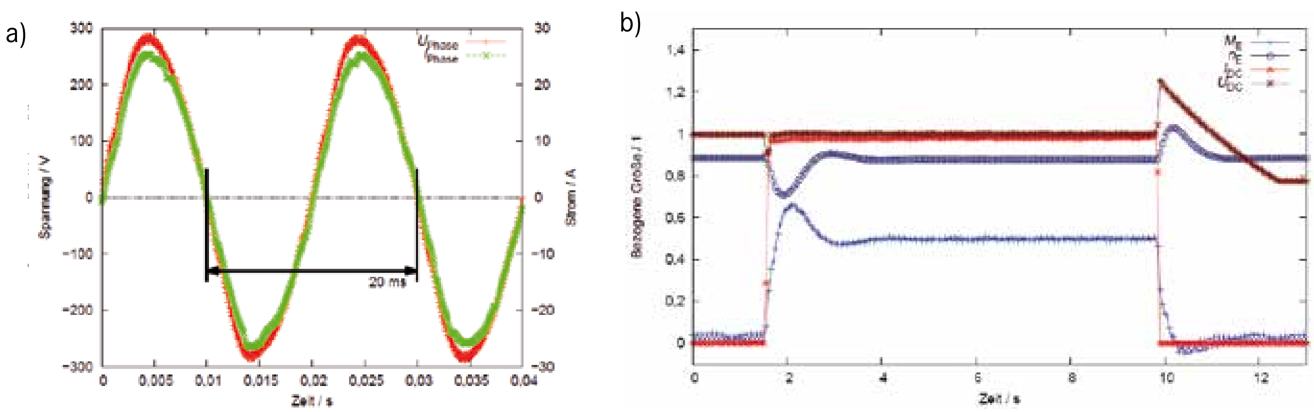
Power flow of PTO generator with braking chopper and insulation monitor

Fig. 5



Activating step-up chopper, Ch1–3: 0,5/Div. – normalized values: 2 volt is 1, Ch4 10 mV equals 5 A (a),
applied load, Ch2–4: 0,5/Div. – normalized values: 2 V equals 1 (b)

Fig. 6



1x230 V output: sinus curve at full load (a),
3x400 V output: characteristics of torque (M_E), revolution speed (n_E) and DC link values (U_{DC}, I_{DC}) at full load (b)

q-axis current goes to a certain level to load the DC link again and hold the voltage. As a result the DC-link rises to the reference value. The difference is is only for about 10 ms. The i_d-current, which is only used for field weakening purposes, remains zero (Ch4).

In **Figure 6** measurements of the isolated network operation output mode is shown. **Figure 6** (a) shows the sinusoidal voltage and current at the 1x230-V-mode at full load. **Figure 6** (b) shows the 3x400-V-mode. In the idle mode a nominal load is applied. The DC link voltage has a slight breakdown, more current is requested, therefore the torque on PTO is higher, thus the revolution speed of the PTO has a slight breakdown too. Depending on the dynamic of the controllers a steady-state is reached after some time. In the case of load shedding (at 10 s) the DC link voltage rises excessive, the breaking chopper is activated and the PTO generator switched off, to be reseted externally. The DC link voltage drops down to the level of the corresponding induced voltage

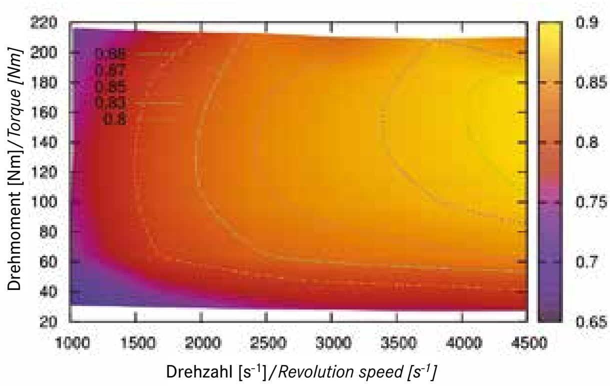
Besides the DC and AC output different PMSM with various agricultural usages were tested:

- outer runner tubular motor: special design, for example a mowing conditioner [7]
- gear motor: low revolutions needed, like hay rake [2], cultivator roller, ...
- gearless drives: high revolutions, like mower, fertiliser spreader, ...

Typical dynamic requirements of agricultural application could be fulfilled. Additionally the efficiency of every PTO unit - motor combination was measured. In **Figure 7** is an example for a geared PMSM presented. In a wide range a very high efficiency, typical for that kind electric drive. Some other maximum efficiencies are: [6]

- Generator: PTO shaft/3-phase: 94 %, PTO shaft/DC link (constant voltage): 92 %
- Motors: geared: 88 %, gearless: 89 % (DC/shaft), tubular drive: 95 % (3ph/shaft)
- 3x400 V / 1x230 V: 98 % (DC/ohmic resistance)
- Field test: 84 % (PTO shaft/3 phase motor input)

Fig. 7



Efficiency map of a geared motor (DC link to shaft)

All the test bench and field test measurements where done sensorless using the back-EMF model at high speeds (15 % and above) and the INFORM-model at low speed and standstill [8]. Closed loop control of electric drives without rotation and position sensors is highly sophisticated for agricultural usage, due to low costs and maintenance free operation in a rough environment.

Conclusions:

Compared to various other types of PTO-generators available on the market the DC-link voltage is independent of the motor speed on a wide range. No gear box is uses, therefore the fail safe time increases and maintenance costs degrease. Various output modes supply lots of possibilities. The sensorless controlling of PMSM is state of the art. The PTO-generator can be used in field as well as a stationary power supply. With three-point hitch and AEF-standardized plugs as interfaces setting up is easy.

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Notes

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