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AUXILIARY POWER SUPPLY – BASED ON PHOTOVOLTAIC ENERGY

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Taking into account that power generation is totally changing right now, also providing state of the art net services like net reliability for example need to be discussed again. This paper introduces a new auxiliary power supply based on a combination of a converter, generator and photovoltaic generator, allowing the support of uninterruptible power supply. Depending on the demanded power the system can run in an idle mode that supports net services like compensating reactive power. In case of a net collapse is also offers a short term boost condition to stabilize the supply without starting the conventional generator. This all is achieved by introducing a new combined converter, which offers a cheap realization by a applying a new modulation method. For state of the art auxiliary power supplies the new modulation model also can be updated to the existing hardware to improve these systems.

Key words: photovoltaic, power supply, converter, generator.

ДОПОМІЖНЕ ЕЛЕКТРОЖИВЛЕННЯ НА БАЗІ ФОТОГАЛЬВАНІЧНОЇ ЕНЕРГІЇ

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Лібералізація електроенергетичних ринків висуває все більш високі вимоги до режимів обслуговування мереж; наприклад, компенсація реактивної потужності повинна здійснюватися по-новому. У даній роботі надано систему аварійного забезпечення енергії, що складається з комбінації перетворювача перемінного струму, електричного генератора й генератора сонячної енергії. Дана компоновка дозволяє, залежно від напрямку потоку енергії, забезпечити аварійне постачання мережі або забезпечити компенсацію реактивної потужності. Це забезпечується за допомогою включення в систему нової модуляційної техніки, яка може бути адаптована в уже працюючі системи.

Ключові слова: фотогальваніка, електроживлення, перетворювач, генератор.

PROBLEM STATEMENT. Auxiliary power supplies very often are situated at positions which hardly can be reached. Therefore having a service free supply would be the matter of choice; however it is very expensive to be realized. In this approach a cheap and efficient supply is introduced which combines photovoltaic energy with a conventional combustion engine within one converter.

EXPERIMENTAL PART AND RESULTS OBTAINED. Fig. 1. indicates a typical auxiliary power supply consisting of a dc/dc-converter, connected to a battery (1) and a generator, driven by combustion engine, which is not highlighted (2).

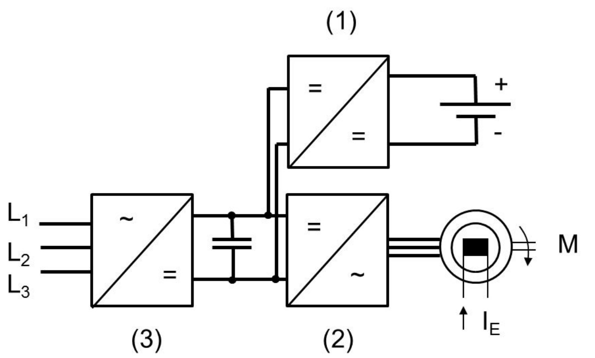

Figure 1 – Sketch of a typical system setup for an aux-iliary power supply

Both (1) and (2) are generating a constant voltage (dc-link). The dc-link is connected to the net (L1–L3) over another converter (3) which if needed supplies the net with power from the dc-link.

In case the net is to collapse (3) converts energy from the dc-link into the net and prevents the collapse. The energy on the dc-link instantly needs to be delivered, what is done within two steps. First, (1) takes the needed energy out of the battery and stabilizes the dc-voltage. At the same time (2) is starting its combustion engine. Once this runs, (2) takes over and (1) does recharge is battery. Finally when the battery is charged, (1) is shutting off.

As soon as the dc-link voltage drops (energy is demanded from the auxiliary power supply), the combustion engine is to be started what very often results in an energy offer much greater than the actual energy demand. This control strategy works absolutely perfect however somehow is inefficient and ends up in increased regular service intervals needed to fill up the tank.

One alternative to extend service intervals is indicated in Fig. 2, where the actual system is extended by an additional dc/dc-converter, connected to a PV-generator (4). The advantage of this constellation is that the auxiliary power supply can supply the amount of available PV-energy without running the combustion engine. This increased energy offer can stabilize the dc-link voltage in terms of small net collapses like net flickers and prevents the combustion engine from being started. However in this constellation an additional converter is needed what costs money. Furthermore a combined control strategy is needed to raise the efficiency gain. Buying individual components with an additional setting up of a system is not enough. Finally this constellation needs a lot of space including cooling what makes this approach unattractive.

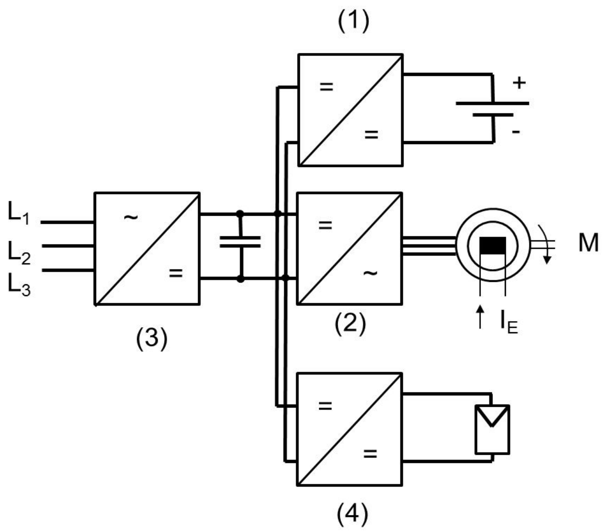

Figure 2 – Auxiliary power supply including photovoltaic energy

New Topology: In this paper a new topology is introduced with identical function by less price and space. The major change is a combination of one of the dc-sources (for example (4)) and the combustion engine converter (2) within one combined converter (5). To build up this combined converter, the generator needs to be built up in a star point or neutral point constellation where the star point itself can be connected by an additional connector. In principal the only hardware change is based on connecting (4) without the dc/dc-converter over a diode and an additional inductivity at the star point of the generator. The original dc/dc-converter of (4) is not needed anymore. The principal setup of the combined converter, fitted with 5 connections, is indicated in Fig. 3.

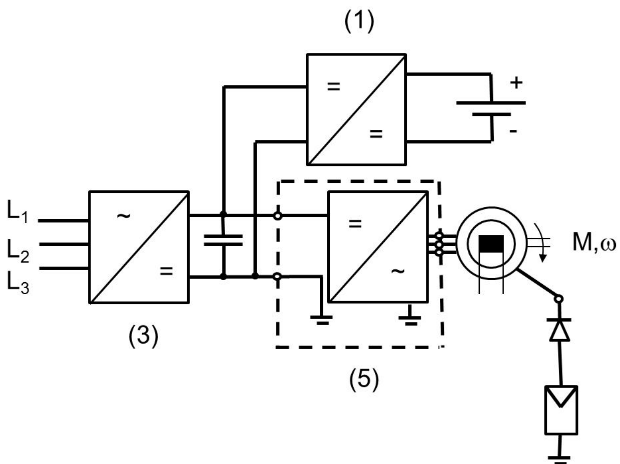

Figure 3 – Principal sketch of the combined converter

From outside, the converter (5) cannot be distinguished from a regular converter. The difference can be seen by a look at the system, where one of the dc-sources, in our case (4) is directly connected to the star point.

Inside the combined converter (5), a standard B6-converter topology is taken which is connected to the generator. The generator itself is mechanically connected to a combustion engine which can turn the generator. The star point of the generator is connected to the PV-string over a diode. An additional inductivity is placed in serial to the diode to increase the efficiency.

Fig. 4 shows an electrical equivalent circuit consisting of (5), generator and PV-string.

A first order model approach of the PV-string is done by a dc-source. This electrical setup is realized as a simulation model within a combination of the software Matlab and PLECS.

The taken parameters are as followed: Dc-link voltage UZK=400 V, phase inductivity LP=50 μH, additional PV-generator inductivity LS=5 mH, phase resistance RP=1 mΩ, and the synchronous generated voltage is set to UPH, x(t) = = 50 V·sin(2π·50s-1·t+2/3π·(x-1)) with the range of x from 1 to 3.

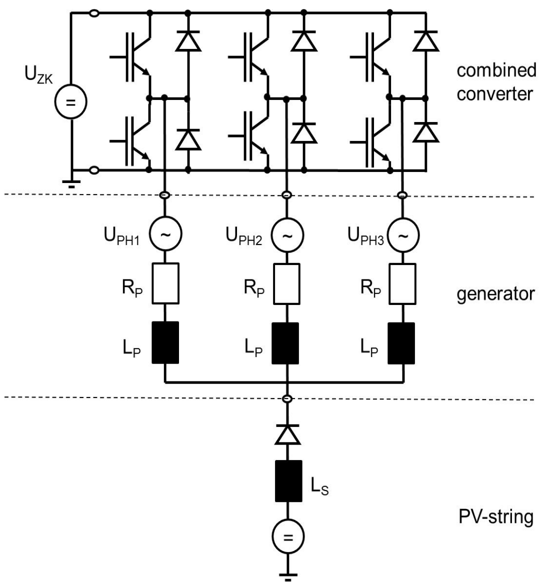

Figure 4 – Sketch of the simulation model in PLECS

In the first step, the connected PV-source is neglected. Once the combustion engine is running, the synchronous generated voltage, no matter if it is generated by permanent magnets or by a separate excitation, generates a voltage UPH,x at the connections of the generator Now the converters task is to rectify the three 2/3·π phase shifted voltages and supply the dc-link with energy. A controller determines the power that is needed. This only parameter the controller has to affect can be described by a modulation factor m (in the range of 0 to 1). The larger m, the more power is taken from the generator. Beside m the arithmetic average of each phase can be set within a certain range. It can be shifted up and down, as long as the peak values of each individual sine do not overcome the supply voltage or drop below ground potential, or in other words, do not start clipping

For converting the energy from the synchronous generated voltage to the dc-link, three appropriate sinuses need to be generated at the generators connectors, realized by the hardware switches. This is realized by driving the switches with a fixed frequency pulse width modulated signal having the duty cycle D. D itself is not constant but consists of a sine of amplitude m having a frequency of the rotation speed multiplied with the pole pair of the generator (in our case it is set to 50 Hz). However in D there is one degree of freedom left, the average potential. This average potential can directly be influenced by an offset duty-cycle Doff which is between 0 and 1. Summing up both parts, the total duty cycle for the hardware switches can be described, what is done for one of the switches as followed:

$$D = Doff + m \cdot \sin(2\pi \cdot 50\ s\text{-}1 \cdot t).$$

The shown D, which in total must not exceed the values 0 and 1, does not include any kind of field suppression, as is not needed in the generator mode and also assumes a constant rotation speed. Now multiplying D with the dc-link voltage UZK directly leads to the phase potential at the generators connector. The average phase potential of one period can be derived as Doff times UZK.

In our case the averages (Doff) of all phases are set equal. For this case no effect on the generators function appears by changing the averages simultaneously because the generator only sees the difference of each phase to its neighbor not the absolute value. Furthermore the star point voltage also takes the average values of the phases. Normally this degree of freedom is used for minimizing switching effects, what is possible for a fixed Doff. Plenty of papers cover this topic with the purpose of increasing the efficiency [1]. However improving switching losses by modulation, typically higher ripple currents on the dc-link capacitor are generated, what shifts the power dissipation from the switches to the capacitors. In addition minimizing switching losses by a variable Doff typically do cause higher iron and cupper losses within the generator due to sharp steps within the duty cycle. In total it is difficult to point out an ideal modulation what leads to the fact, that state of the art inverters very often still run without any specific modulation, as described with an fixed Doff = 0.5. All these power dissipation effects are not part of this paper.

In this paper we introduce a variable arithmetic average Doff :

As pointed out earlier, Doff directly is correlated with the arithmetic average of the phase voltages and thus the real average star point potential. In case of three identical phase inductivities, you can derive the star point potential as the average of all three arithmetic averages whereas in our case, all three of them are the same.

As pointed out earlier, the generator electrical only is affected by the three connector potential e.g. potential differences of these three. This indeed means that overlying the same average voltage to all connector potentials does not affect the generators power at all.

This is shown in fig. 5 where the output power for three different Doff (0.3, 0.5 and 0.7) is shown, keeping all other parameters the same. As can be seen, the output power does not change at all although three different phase averages are set. The independence between average value and output power remains as long as the peak values do not exceed the upper (supply voltage) or lower (ground potential) supply potentials.

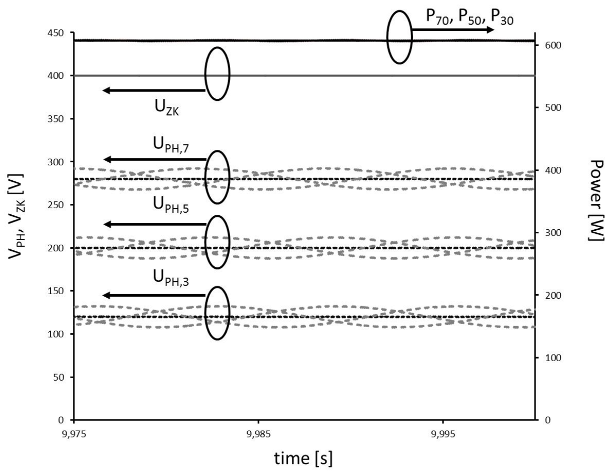

Figure 5 – Simulation of a generator power of 610 W for three different Doff (0.3, 0.5, 0.7) while remaining all other parameters unchanged

However one limitation comes up once the star point potential drops below the potential of the connected PV-string. As long as the potential of the star point is higher than that from the PV-generator, the blocking diode prevents current running in the PV-generator. Once the star point potential drops below the PV-potential, a dc-current is injected into the star point of the generator by the PV-generator. Luckily voltages and no currents are set at the generators connectors by the inverter what allows the PV-current /-power to positive interfere with the generator current / power.

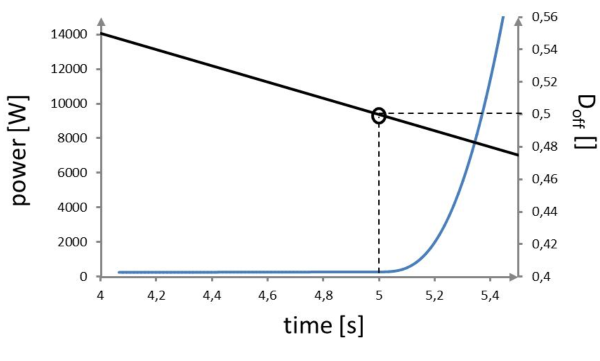

Figure 6 – Output power versus time for a moving Doff

This is shown in Fig. 6, where the output power injected into the dc-link for a constant dc-link voltage and the constant set of boundary conditions as described earlier is highlighted. The PV-voltage is set to 200V.

The only variable parameter is Doff which decreases with a speed of 0.05/s and reaches the value of 0.5 for a time of 5s. In the first part of the chart, the output power almost remains constant at around 250 W (t<5 s). Suddenly a strong increasing in output power can be seen (t>5s). The reason for this effect comes from Doff, which passes the value 0.5 at t = 5 s. Doff = 0.5 correlates with a star point voltage of 200V, and therefore becomes equal with the PV-voltage in this simulation example. If the star point voltage drops below, PV-power is inserted into the system. In our case, the PV-power is only limited by a resistor value of 10 mΩ, which is modeled as a parasitic in the LS. The very low internal resistance of the PV-model causes the high output power of the PV-generator.

The example shows that PV and generator can be driven in parallel within one converter and both power the dc-link. However, it is difficult to determine how the power for either PV or of the generator can be controlled. To get a closer look insight into the behavior, a dynamic example is taken. In the simulation, the modulation is turned on at the time t=0 s. With a time of t = 3 s, Doff starts to decrease from 0.6 to 0.4 (t = 7 s) and hits the 0.5 value at t = 5 s. All other parameters remain unchanged.

Fig. 7 shows the simulation results. Different power levels versus time on a logarithmic power axis are plotted and need to be investigated. First of all, a closer look on the total output power is done. The total output power is measured as a power that is injected on the dc-link and therefore indicates the total output power of the setup no matter where it comes from. Mainly three areas can be identified. Within the first area directly after starting the simulation, the power is increasing until it remains almost constant for a certain time (0.5–5 s). Afterwards the output power starts increasing again.

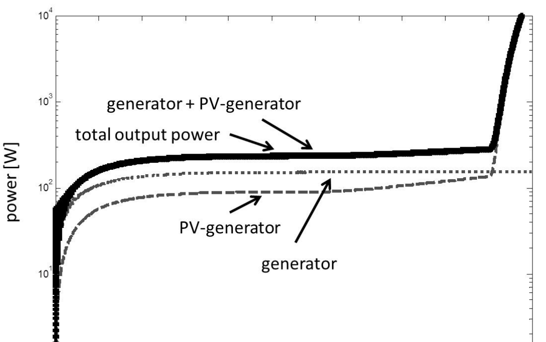

Figure 7 – separation of different power contributions to the total output power

To get a better understanding about why the total output behaves like this, further steps are done. First of all we take a look at the PV-power, directly measured at the PV-source. Once the modulation is turned on, the PV-power increases from zero to around 70 W. The slow increase is related to the PV-inductivity and the phase inductivity, together with the phase resistance. All together form a RL-low pass which delays the output power. However the question arises about how a PV-power can be generated as long as the star point potential is higher than the PV-potential (Doff > 0.5 for this time). The answer is because the output power itself is generated due to a remaining voltage ripple from the real pulse width modulation. The inductivities act as a low pass (in terms of the high switching frequency) but a small voltage ripple at the star point remains. The star point potential is close to the PV-potential and partly dips below the PV-voltage, causing a light average current and therefore output power of the PV-generator.

After having an almost constant power level of the PV-generator, the power value starts increasing again with a time of t = 3 s. This is the point where Doff starts decreasing. The already described voltage dip below the PV-potential increases with decreasing average value of the star point and with it the PV-output power increases. At the point of Doff=0.5, the star point potential drops below the PV-potential and PV-power e.g. PV-current increases.

The PV-power is not sufficient to describe the total output power. Therefore the generator power needs to be derived as well. To calculate the generator power, first all the three phase currents are summed up. While in a general three phase generator with star point configuration, the sum of all currents must be zero, in this constellation an average is generated by the PV-generator. Therefore the sum indicates the average or PV-current. To calculate the generator power, one third of the average is substracted from the individual phase currents. The remaining equivalent generator current finally is multiplied with the synchronous generated voltage to get the phase dependent generator power. Summing all three phase powers up ends in the total generator power, and is highlighted in the Fig. 7. As can be seen, the generator power also relies under a RL low pass (phase inductivity and phase resistance) after turning the modulation on. After the RL-time delay, the generator power reaches a constant value of around 250 W. With passing time, there is no change in the generator power anymore, even not with decreasing Doff .This means that a drop of Doff below 0.5 does not cause any change in the output power. This behavior should be like this because the generators speed and the taken output power that depends on m, remains unchanged. This behavior indicates, that the PV-power and the generator power can be distinguished from each other for each situation, even in dynamic behavior.

Finally, the PV-power and the generator power is summed up and directly lies on the line of the total output power. By zooming very close to the line, it can be seen that the curve achieved by summing up the PV-power and the generator power is slightly above the total output power on the dc-link, what originates from the power dissipation of the resistors and the series resistances of the switches.

The power constellation needs to be controlled. Fortunately, the generator power and the PV-power are absolutely independent of each other. This directly leads to the fact, that the space vector oriented control, which is typically applied for the generators control directly can be taken for controlling the generator power, as long as the measured phase currents are corrected by the overlaying average current.

The other way round, the PV-power can be controlled by the average power, what normally is controlled with an typical maximum power point tracker (MPPT). The power itself can be calculated by a product of the sum of all three phase currents multiplied with the average potential of the generators connectors.

Having the ability of free control of two different energy sources within one inverter opens a new degree of freedom. For example, it is possible to start the generator with space vector control as long as the MPPT delivers enough energy.

CONCLUSIONS. A new modulation method is introduced combining two energy sources (DC and AC) within one inverter. A new modulation method allows the free control of both sources, so that energy of one source can be used to boosted the net or also the other way round can be done to power the generator by PV without consuming power from the dc-link. This constellation strongly increases reliability of these type of systems and also can be applied to several other constellation.

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ВСПОМОГАТЕЛЬНОЕ ЭЛЕКТРОПИТАНИЕ НА БАЗЕ ФОТОГАЛЬВАНИЧЕСКОЙ ЭНЕРГИИ

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Либерализация электроэнергетических рынков выдвигает все более высокие требования к режимам обслуживания сетей; например, компенсания реактивной мощности должна осуществляться по-новому. В настоящей работе представлена система аварийного обеспечения энергии, состоящая из комбинации преобразователя переменного тока, электрического генератора и генератора солнечной энергии. Данная компоновка позволяет, в зависимости от направления потока энергии, обеспечить аварийное снабжение сети либо обеспечить компенсацию реактивной мощности. Это обеспечивается посредством включения в систему новой модуляционной техники, которая может быть адаптирована в уже работающие системы.

Ключевые слова: фотогальваника, электропитание, преобразователь, генератор.

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