STANDBY POWER SUPPLY USING ALTERNATIVE ENERGY THROUGH COGENERATION TECHNOLOGIES

Dr. Jardan, R. K. *, Dranga, O. (Ph.D. Student)*, **Bereknyei, D.** (Ph.D. Student)*

* BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
H-1111 Budapest, Budafoki 8. Hungary.
Tel: +361-463-2338, Fax: +361 4633163 e-mail: jrk@elektro.get.bme.hu

ABSTRACT

A special co-generation system, developed for producing electric and heat energy from low pressure saturated steam or some other working medium has been developed. The system consists of a high speed turbine, coupled to a three-phase permanent magnet synchronous generator, a three-phase AC/AC converter and a microprocessor supervisory control unit. The main purpose of the system is to produce electric energy, that can be utilised directly to supply loads in stand-alone mode or it can be fed back to existing utility mains. In the latter case the converter, connected in parallel to the mains, can serve also as a source of reactive power and higher harmonic current components, i.e. the converter, by changing its control method, can be turned into a system providing not only active power, but functioning as a complete active filter or a.c. line conditioner at the same time. In the paper a further feature of the system, its ability to serve also as a stand-by (SPS) or uninterruptible power supply (UPS) is presented in some detail.

1 INTRODUCTION

The paper describes a special system designed to be used as an alternative power source for telecommunication equipment or as an UPS-system.

The system is based on the application of co-generation principle, that makes it possible to generate electric and heat energy by utilising alternative renewable and waste energy sources. The basis of the solution is a system that consists of a high-speed turbine coupled to a three-phase synchronous generator, a three-phase AC/AC converter and a microprocessor supervisory control unit. The function of the system is to utilise the energy content of some working medium, such as steam, gas or pressurised fluid, by a special turbine. A more detailed description of the system can be found in [1]. The turbine is developed for various working media of low energy content. Generally, the system, beside heat energy produces electric energy, that can be utilised directly to supply loads in stand-alone mode in isolated rural areas as general-purpose power supply for telecommunication and other loads or feeding it back to existing utility mains. The additional feature of the system that makes it possible to use it as an a.c. line conditioner is presented in [2].

As the energy source of the system is different from the mains, it offers the possibility to use it as an SPS or UPS. In the parallel mode of operation, when the system feeds energy back to the mains, during mains failures, it can serve as a standby power supply or UPS for a selected group of loads including telecommunication equipment.

A possible advantage of the system is that it can use alternative energy sources that are suitable for producing saturated or superheated steam with low or medium pressure, thus it is applicable in telecommunication systems even in places where electric energy is not directly available. In most cases the electric energy can be produced within co-generation or less frequently in direct generation process. The alternative renewable energy sources include solar energy (direct solar steam system or solar energy with heat exchanger), geothermal energy (with or without heat exchanger) and biomass energy. Various waste energy sources can also be utilised by applying the system. These include the energy extracted from the process of pressure reduction in steam, gas and fluid networks and the energy that can be recovered in the process of seawater desalination.

2. Description of the system

Various configurations of uninterruptible power supply systems are available to increase the reliability of the energy supply and improve the overall performance. Development of an up-to-date high performance system requires careful attention to every detail of it. In a previous paper [4] solution to problems of the inverter stage was presented, here the questions of application of renewable energy sources is discussed in some detail.

At the beginning of static UPS applications the system was built of a controlled rectifier an inverter (including the filter) and a battery connected to the DC link. It soon became evident that this simple arrangement had two basic shortcomings. First, if any problem occurred in the inverter operation, the supply of the load was lost, even if the mains was present. The second problem is connected with the internal impedance of the inverter and filter stage. In case of a transient load increase, the output voltage had relatively large drops, that frequently resulted malfunction of sensitive loads.

Great improvement in system performance was achieved by the introduction of fast-acting static switches.

In the scheme shown in Figure 1 static switch SW is closed in normal operation while static transfer switch STS is open. In case of failure or excessive voltage drop detection, SW is open and at the same time STS is closed. This way a large current transient can be supported by the mains. If the load current returns to normal and output voltage of the inverter is within tolerance, the load can be transferred back to the inverter.

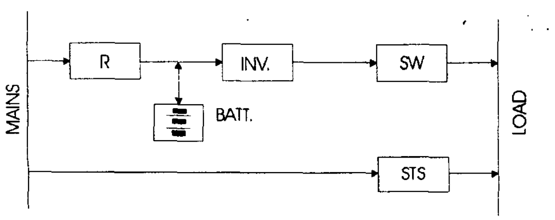

Figure 1. Block diagram of a UPS configuration

A brief description of the system is given for the application in steam networks, however, it should be emphasised that the key elements and the basic principles of the operation are the same in the case of other energy sources and working media.

Applying the turbine-generator system, the functional block diagram shown in Figure 1. has to be modified, as the rectifier is supplied by the generator instead of the mains. The generator, driven directly by the turbine, is a machine of special construction. Due to the high speed and the requirement of high reliability, a permanent magnet solution has been selected. The output voltage of the generator is fed to the rectifier R that is followed by the inverter INV. The resulting AC/AC converter connects the generator of variable frequency and output voltage to the utility mains of fixed voltage and frequency.

A block diagram of the turbine-generator-converter system presenting the main units is shown in Figure 2. The working fluid is fed to the turbine through safety valve SV and control valve CV. Turbine T is directly coupled to generator G that supplies the input of the three-phase AC/AC converter, while the output of the converter is connected to the utility mains. In the basic arrangement of the system there are two parameters to be controlled. One controlled parameter is the outlet pressure of the turbine that is changed by the inlet quantity of the working fluid through the control valve, i.e. a flow control actuator.

The other controlled parameter is the speed of the turbine-generator set. The micro controller unit controls the output quantities of the converter by accepting signals from the supervisory controller and the output power sensor S2.

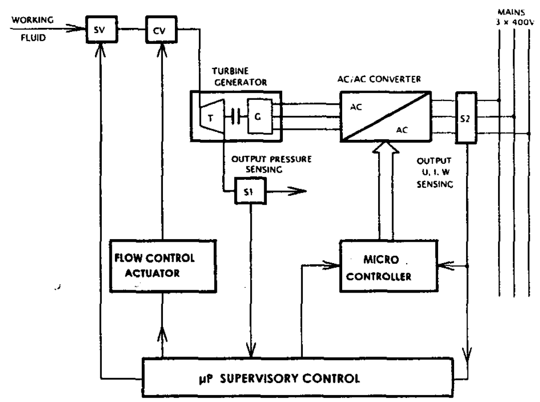

Figure 2. Block diagram of the standby power supply studied

2.1 Operation of the system

The working fluid fed to the turbine through valves SV and CV produces torque in the turbine that is transferred to the generator connected to it by a clutch. The electric power obtained at varying voltage level and frequency is to be fed back to the utility mains of 400 V and 50 Hz by the help of the AC/AC converter.

The output power of the converter is controlled according to the reference signal of the control unit, given by the speed controller. A pressure controller loop keeps the pressure of the working fluid at the outlet constant corresponding to a reference signal.

There are two basic modes of operation of the system when functioning as an SPS or UPS.

2.1.1. Stand-alone or Island Mode of Operation

In this mode the loads are directly supplied by the converter of the turbine-generator system. Theoretically, in this mode the turbine-generator system, without any additional measures, is functioning like a UPS. Naturally, the group of the loads have to be selected to match the output power of the UPS. The control strategy of the system is based on controlling the input power on the mechanical side to ensure power equilibrium between the mechanical and electrical side.

2.1.2. Parallel mode.

In this mode both the turbine-generator system (UPS) and a selected group of loads are connected to the mains. In normal mode the turbine-generator system feeds all the power back to the utility mains, available on the mechanical side, that is automatically ensured by the speed regulation of the machine set. In case of mains failure the group of loads is disconnected from the mains by opening the static transfer switch STS and further on the power will be supplied by the turbine – generator system. Apart from some switching transients the power supply of the loads can be regarded continuous. When the static transfer switch is opened, the control strategy of the turbine-generator system has to be changed to correspond to the stand-alone mode. After the mains returns to normal, the system can be restored to the original state.

3 Power Factor Correction

In an industrial environment a considerable portion of the loads have a poor power factor resulting from low cos φ and high harmonic content of the load current. The principles of compensating the reactive power and the higher harmonic content will be discussed next.

3.1 Compensating Reactive Power

Assuming that the mains current contains only fundamental component but the power factor needs correction, reactive power has to be supplied to the mains. If the power source is suitable to change the reactive power supplied, a closed-loop power factor compensation can be built by sensing the power factor at a point of the network where compensation and controlling the source of reactive power is needed to supply the required amount of reactive power. When the power capability of the reactive power source is limited, it makes it only possible to improve the power factor or to compensate the power factor of a selected group of loads. This is the case with the converter of the turbine-generator system as the rated power of the unit is generally considerably lower than the power level required e.g. by a factory.

If the reactive power of the loads is Q_L, to obtain unity power factor, a reactive power Q_L has to be fed to the mains. By sensing the reactive power needed, the converter can be controlled in such a way that it will produce the requested power components The control unit has two input accepting reference signals P^* and Q^* that determines the active P and reactive Q power independently. For this purpose the amplitude and the phase of the internal voltage of the controller has to be controlled.

A converter dimensioned for rated current can supply reactive power only if the active component is less than rated. To produce reactive power by the converter at rated active power evidently needs over-dimensioning some parts of the converter. A 50 % over-dimensioning in current ensures that reactive power can be supplied, in the range of 110 to 150 %, depending on the active power needed.

4 Simulation and test results

The idea described here has been checked by computer simulations and laboratory tests.

A turbine generator converter system with an output power of 20 kW and 25 kVAr has been built and tested. The system is installed in an industrial environment where the Total Harmonic Distortion (THD) of the mains voltage is unusually high due to rectifier type loads. The average THD of the mains was over 9 % and it offered good opportunity to demonstrate the effect of the converter on the power quality.

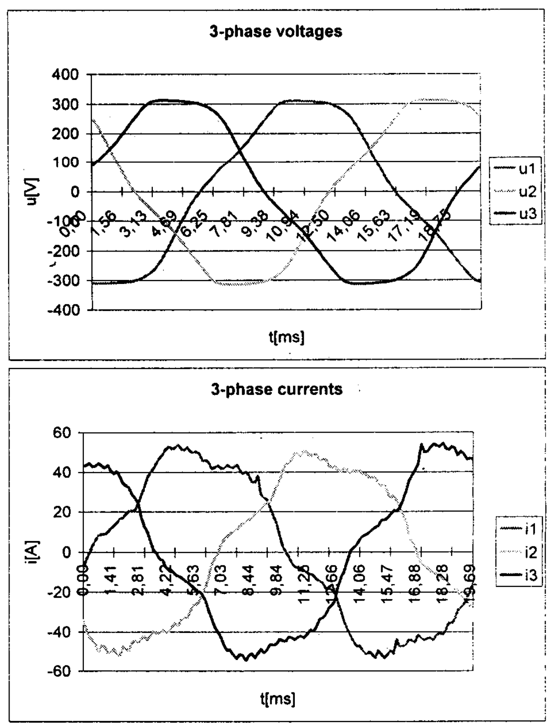

Figure 3. Test results. Upper traces line voltages, lower traces converter output currents. Output power: 24 kVAr

Signal	1st phase	2nd phase	3rd phase	Total
Ursm	223.43	226.04	225.73	
thd(U)	7.84	7.95	7.71	
Irsm	36.23	34.18	36.60	
thd(I)	12.53	11.62	11.89	
S(kVA)	8.10	7.73	8.26	24.08
P(kW)	-0.12	-0.46	-0.03	-0.61
Q(kVAR)	-8.09	-7.71	-8.26	-24.07
cos φ	-0.01	-0.06	0.00	-0.03

Table 1. Laboratory test results

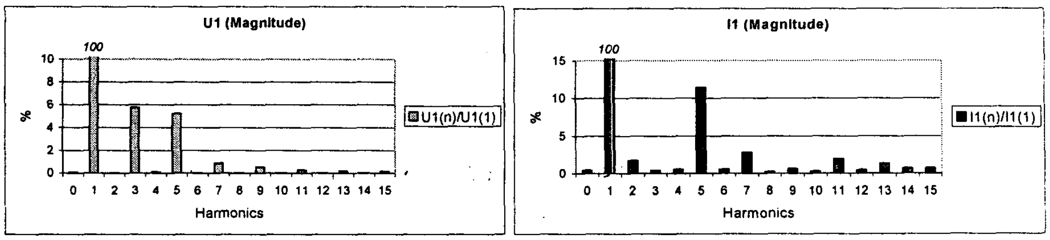

Figure 4. Harmonic voltages and currents test

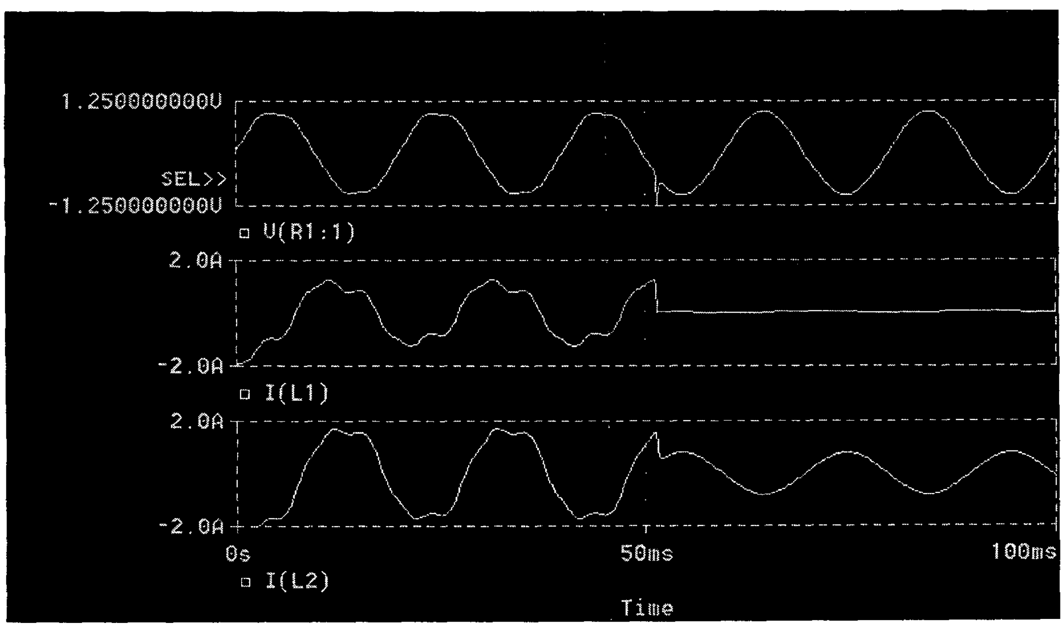

Figure 5. Simulation result. Transient of a mains falilure. Upper trace: load voltage, middle trace: mains current, lower trace: inverter output current. Values are given in [pu].

The results were recorded by using network analyser equipment inserted between the output of the converter and the mains. The equivalent circuit of the mains, from measured values, was calculated as R_m=0.3 Ω (ohmic resistance) and L_m= 508 μH (inductance). The converter filter parameters are R_c=0.05 Ω and L_c=2.5 mH.

Figure 3. shows that the shape of the output voltage and the current is different from the ideal sinusoidal one due to its compensation affect on the network. These results are displayed in Table 1.

During the above test the converter supplied 24 kVAr reactive power to the mains and the THD was reduced from 9.4 % to 7.8 % corresponding well to the calculated attenuation coefficient k_D=0.83.

Using the measured harmonic components of the line voltage and an above parameters the system was simulated taking accurately into account the operation of the converter with a switching frequency of 10 kHz and applying a unipolar PWM.

In Figure 5. the results of a simulation run are shown. In a system operating in parallel mode, a mains failure is assumed at the instant of 50 ms. The static transfer switch is opened and further on the load current is supported by the inverter. The output current of the inverter is reduced as the load is assumed to be lower than rated. It can be seen that due to the distorted waveform of the mains, the output current of the inverter contains high harmonic content in normal operation, while it becomes sinusoidal in the stand-alone mode. (A linear load is assumed).

5. Conclusion

In the paper a special power system, that consists of a high-speed turbine coupled to a three-phase synchronous generator, a three-phase AC/AC converter and a microprocessor supervisory control unit, was presented. The system is designed to operate using alternative energy source that is suitable also to serve as a standby or uninterruptible power supply. A control strategy, easy to implement, ensures closed loop control of the power factor and at the same time the power quality is favourably affected.

6 References

1. Jardan, R.K. *Generation of Electric Energy by High-Speed Turbine -Generator Sets.* Proceedings of Intelec'95 Conference October 29-November 1. The Hague, The Netherlands, pp.664-670

2. Casadei, D.-Grandi, G.-Jardan, R.K.-Profumo, F. *Control Strategy of a Power Line Conditioner for Cogeneration Plants.* PESC'99, Power Electronics Specialists Conference, Charleston, South Carolina, US. June 27-July 1, 1999.

3. Jardan, R. K -Nagy, I.- Korondi, P. Masada, E - Nitta,T.- Ohsaki, H. *Power Generation System for Utilising Alternative Renewable and Waste Energy* IPEC-Tokyo-2000, April 3-7, 2000 Tokyo

4. Jardan, R. K. . *Problems of Static Switches in Three-Phase UPS Systems,* Proceedings of the 22nd International Power Conversion Conference, June 25-27, 1991, Nuremberg, Germany