Regenerative energy sources applicable to joining processes

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1. Introduction

The thermal energy received from the Sun, measured at the level of the Earth surface is 1000 W/m2, by direct and diffuse radiation, as shown in the fig.1. The utilizing potential of solar energy in Romania is 1450…1600kWh/m2/year in the South, respectively 1250…1350kWh/m2/year in the majority of the zones [1]. In 2011, the reference investment price for photovoltaic systems was 1950 Euro / kWp. For the regulation of the subvention for non-conventional and regenerative energy, the

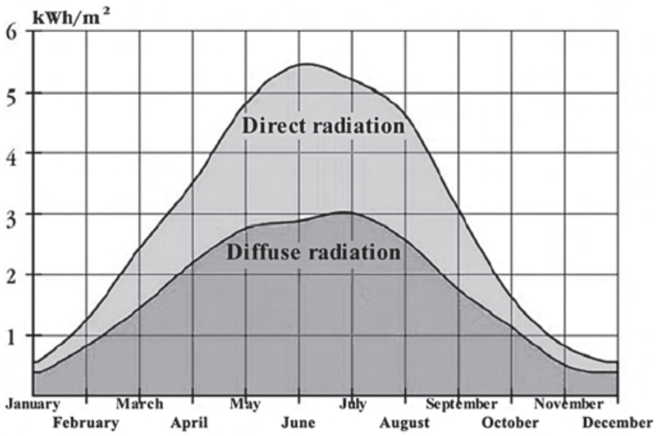

Figure 1. Solar direct and diffuse radiation components [1]

Law 220 of 2008 was given, republished in the Official Monitor of the 13th of August 2010. This sets green valuable certificates for electric energy produced by conversion systems.

2. Analyse of the energy consumption of some joining processes

2.1. Manual Metal Arc Welding

The consumption of electric energy [2]-[3] depends mostly on the technical characteristics of the welding source and the applied welding parameters.

The technical time rate [4] is assessed, in the measuring unit [min / workpiece], with the equation:

$$N_T = T_{pi} / n + (\Sigma^{k}_{j=1} T_{opi\,j} \cdot l_j + t_{ap}) \cdot K_d \cdot K_o \cdot K_p \qquad (2.1)$$

in which: $T_{pî}$ – time for preparing and ending, in min/lot; n- number of the identical workpieces to be executed; T_{opi} – incomplete operative time; t_{ap}- auxiliary time related to the welded workpiece, in min/workpiece; K_d- coefficient considering the operation at the working place; K_o- coefficient related to the time for rest and physiological necessities; K_p - coefficient for the labour productivity.

Electric energy consumption is calculated by the equation:

$$E= \Sigma_j I_{sj} \cdot U_{aj} \cdot t_{bj} \cdot l_j / (6 \cdot 104 \cdot \eta) + P_0 \cdot (N_T - \Sigma_j t_{bj} \cdot l_j)/60 \qquad (2.2)$$

in which: I_{sj} - welding current intensity, in A; U_{aj} - electric arc voltage, in V; t_{bj} - specific basic time, related to the welding bead length j, in min/m; l_j - welding bead length, in m; η- electric efficiency of the welding source; P_0 - open-circuit power consumption of the source, in kW; N_T - technical time rate, in min/workpiece.

The specific consumption is computed by the relationship:

$$Especific = E / (\Sigma j\ lj) \qquad (2.3)$$

The consumption $E_{specific\ EI}$ = 1.50135 kWh/m was assessed.

2.2. Gas metal arc welding (MIG/MAG)

Based on similar equations, the technical time rate and the energy consumption were determined for two cases of gas metal arc welding. The consumption is $E_{specific\ MAG}$ = 0.51786 kWh/m (without no-load run) and 0.74781 kWh/m.

2.3. Electro-thermal soldering with non-ferrous alloys

Electric energy consumption is assessed by the equation:

$$E = U_{supply}\ I_{supply} \cdot N_T / (6 \cdot 10^4) \qquad (2.4)$$

in which: U_{supply} - supply voltage of the soldering equipment, in V; I_{supply} - supply current of the soldering equipment, in A; N_T - technical time rate, in min/workpiece.

The specific consumption of the 300 W soldering device, for the length llipire of the soldered joint, is computed with:

$$E_{specific300W} = E_{300W} / l_{lipire} \qquad (2.5)$$

The determined extent is $E_{specific\ 300W}$ = 1.40748 kWh / m.

2.4. Ultrasonic welding

The power of an ultrasonic welding equipment on a duty factor DA= 60 % is P= 800... 3000 W.

The time rate is computed by the following relationship:

$$N_T = t_{pi} + (t_{Welding} + t_{Auxiliary}) \cdot K_d \cdot K_o \cdot K_p \qquad (2.6)$$

where: t_{pi} = 5... 8 s is the preparing time; $t_{Welding}$ = 1.8... 65 s is the time for welding or processing, ultrasonic in this case; $t_{Auiliar}$ = 5.5... 6.5 s is the time for auxiliary operations; K_d = 1.3; K_o =1.2 and K_p =1.4 are coefficients for working place attendance, rest time and work yield. For metal workpieces N_T = 27.656 s, for plastic N_T = 20.9432 s and by ultrasonic processing N_T = 158.972 s.

Energy consumption is assessed by the equation [5]-[8]:

$$E = P_{Equipment} \cdot t_{Welding} / (3.6 \cdot 10^3)\ \ [kWh] \qquad (2.7)$$

where: $P_{Equipment}$ – rated power of the welding equipment, ultrasonic in this case, in W; $t_{Welding}$ is the welding time, ultrasonic in this situation. For the three analysed cases, the specific consumption extents are: E_1 = 0.0020833 kWh, E_2 = 0.001500 kWh şi E_3 = 0.05416 kWh.

2.5. Stored energy welding

A stored energy welding equipment on capacitors, of 1400J is analysed, for 3... 6 mm studs. Welding time is 5ms. The maximum welding frequency for 3 mm studs is 8 welds / min. The time rate assessed with the relationship of the previous chapter is N_T = 7.5 s. The specific electric energy consumption for a weld is E= 0.0003888 kWh.

2.6. Stud welding

For equipment of S_n = 1.3...4.0 kW rated power by DA = 60% and welding frequency of 15... 40 welds / min, t_{pi} =2.0...3.2 s; t_{Stud} = 1.4...3.5 s; $t_{Auxiliary}$ = 1.5...2.5 s; K_d=1.1; K_o = 1.05; K_p =1.15 were applied. For Φ5 mm the time rate is N_T = 5.8519s and for Φ16 mm the time rate is N_T = 11.1695s.

With the given equation, the electric energy consumption for a Φ5 stud is E_1 = 0.0005055 kWh, respectively for a maximal diameter Φ16 stud it is E_2 = 0.003888 kWh.

2.7. Laser welding

The laser type HL-124P LCU, made by the company Trumpf, of the category NdYAG, has the installed power of 7 kVA. The operating regime is on pulses, with the pulse frequency f_i = 0...300 Hz. The pulse energy is 10... 50 J. In the case of plastic workpieces welding, the time rate is N_{TMax} = 16.61837 s. Electric energy consumption for a plastic piece is E_{Max} = 0.0097222 kWh.

2.8. Friction stir welding (FSW)

By the friction stir welding [9]-[10] of aluminium plates the time rate is N_T = 352.88 s, for steel plates N_T = 619.968s. For FSSW spot welding of aluminium plates, N_T = 62.232 s.

Electric energy consumption is assessed by the equation:

$$E = [P_{m\,vert} \cdot G_{m\,vert} \cdot t_{vert} + P_{m\,rot} \cdot G_{m\,rot} \cdot t_{rot} + P_{m\,oriz} \cdot G_{m\,oriz} \cdot t_{oriz}] / (3.6 \cdot 10^3) \quad (2.8)$$

in which: $P_{m\,vert}$ = 0.75kW is the rated power of the motor for vertical movement; $G_{m\,vert}$ = 0.70...0.95 is its load level (ralated to 1.0); t_{vert} = 4...12s is its driving time; $P_{m\,rot}$ = 4.0 kW is the rated power of the motor for the rotating movement; $G_{m\,rot}$ = 0.71...1.29 is its level of load; t_{rot} = 15...180s is its drive time; $P_{m\,oriz}$ = 2.2 kW is the rated power of the motor for the horizontal movement; $G_{m\,oriz}$ = 0.55...0.59 is the load level of this; t_{oriz} = 15...180s is the driving time of this. By aluminium plates, the estimated specific consumption is E_{Al}= 0.0696kWh for 0.30m; by steel plates E_{OL}= 0.327kWh; by FSSW spot welding of aluminium sheet places E_{FSSW} = 0.0175kWh.

2.9. Spot resistance welding

The installed power range of the equipments for spot resistance welding is very wide, from less than 1kVA up to 250 kVA. Shortcircuit power range reaches 700 kVA. For a conversion system, only equipment rated up to 4 kVA is taken into account.

2.10. Electro-thermal welding of plastic foils

An equipment for polyethylene foils of 2 x 0.1 mm and polyvinyl chloride foils of 2 x 0.08 mm has the rated power of 1100 W. The time rate is N_{TMax} = 29.9008s, and the specific consumption is E_{Max} = 0.0045833 kWh / weld.

2.11. Polyethylene tubes welding

The installed power of the welding devices for tubes of polyethylene of high density (PEHD) is in the range S_n = 1450...4500 W and duty factor DA = 35...60%. This is a representative case of in-situ application.

The time rate is computed by the following equation:

$$N_T = t_p + (t_{milling} + t_{heating} + t_{pressing}) \cdot K_d \cdot K_o \cdot K_p \quad (2.9)$$

where: t_p = 289s is the preparing time, $t_{milling}$ = 245s is the milling time; $t_{heating}$ = 310s is the time for heating; $t_{pressing}$ = 520s is the time for pressing the tube heads; K_d = 1.1; K_o = 1.05 and K_p = 1.15 are adjustment coefficients. For tubes of 315 mm diameter, the time rate is N_T = 1716.86s.

The electric energy consumption is assessed with:

$$E=[P_{mill} \cdot t_{mill} + P_{stove} \cdot t_{heating} + P_{pump} \cdot t_{pump}]/(3.6 \cdot 10^3) \quad (2.10)$$

in which: P_{mill} = 1.1 kW is the rated power of the milling machine motor; t_{mill} = 18 s is the milling time; P_{stove} = 4 kW is the rated power of the electric stove for heating the tube heads; theating = $\Sigma_i t_i$ = 1364 s is the time for heating; P_{pump} = 1.5 kW is the rated power of the hydraulic pump motor for pressing; t_{pump} = 85 s is the operating time of the pump motor. The electric energy consumption is E = 1.55522 kWh for a weld.

2.12. Cutting and delivering

By the oxygen-acetylene and oxygen-gas flame cutting, the electric power consumption is low, of 0.5... 1.0 kW. The supply from a conversion system is feasible.

By the plasma delivering of pieces from a 10mm x 1000mm x 2000mm steel sheet, for the quotations: t_p = 10 min; $t_{Delivering}$ = 20 min; $t_{Auxiliary}$ = 5min; K_d = 1.1; K_o = 1.05; K_p = 1.15, the time rate is N_T = 22.26... 43.20 min. The electric energy consumption is E_{plasma} = 2.0...4.0 kWh/sheet.

3. Establishing the technical requirements for a solar energy conversion and storage system, applicable to joining processes

3.1. Average power

The average power consumed by the joining process is calculated with the relationship:

$$P_{average} = E / N_T \quad (3.1)$$

where: E is the consumed energy and N_T is the time rate.

3.2. Peak power

The consumed peak or maximal power is computed by applying some coefficients onto the installed power, according to the relationship:

$$S_{Max} = K_U \cdot K_I \cdot S_n \quad (3.2)$$

where: K_U şi K_I are the overloading coefficients for voltage, respectively current; S_n is the rated apparent power of the welding source or equipment. For the soldering, plastic foils welding and polyethylene tubes welding equipment, the peak power is equal with the installed power, because the main consumer is of the resistance kind.

3.3. Number of the photovoltaic panels

The number of the photovoltaic (PV) panels for supplying a joining equipment is determined with the relationship:

$$N_{PV} = P_{Max} / P_{n\,PV} \qquad (3.3)$$

in which: P_{Max} is the maximal or peak consumed power; and $P_{n\,PV}$ = 120...200 W is the rated power of a PV panel.

3.4. Intermittent regime operation with accumulators

A welding source has the possibility of operating on the peak power, higher than the installed power of the photovoltaic panel system, if the system has accumulators. The energy balance needs to be equal:

$$P_{PV} = (\Delta t_{consumption} / \Delta t_{PV})\ P_{consumption} \qquad (3.4)$$

The duty factor of the welding source or equipment in the intermittent regime is:

$$DA = (\Delta t_{consumption} / \Delta t_{PV}) \cdot 100\% \qquad (3.5)$$

In these relationships, $\Delta t_{consumption}$ = 1... 6 hours, respectively Δt_{PV} = 3...10 hours is the charging time (per day) of the accumulators.

3.5. Capacity of the accumulators system

The relationship for the accumulators capacity is used:

$$C_A = P_{consumption}\ \Delta t_{consumption} / (U_A\ \eta\ K_{id}) \qquad (3.6)$$

where: C_A [Ah] is the total capacity of the accumulators; $P_{consumption}$ is the consumed power; $\Delta t_{consumption}$ is the time for executing the joint; U_A = 12V is the rated voltage of the accumulators; η = 0.65...0.75 is the storage efficiency; K_{id} = 0.5...0.75 is the coefficient for partial charging-discharging, in order to increase the operating life. The endurance of the accumulators is 800 days.

3.6. Number of the photovoltaic panels under unfavorable atmospheric conditions

The number of the photovoltaic panels under such conditions is:

$$N_{PV} = (\Delta t_{consumption} / \Delta t_{PV})\ P_{average} / (K_a\ P_{n\,PV}) \qquad (3.7)$$

where: K_a= 0.10...0.95 is a coefficient depending on the unfavorable atmospheric conditions, that reduce the received solar radiation and the energy obtained by conversion.

4. Conversion and storage system, applicable to joining equipments

4.1. Comparing presentation of the technical requirements for a conversion system

In the Table 1, the requirements for the conversion system are presented.

A self-supplying conversion system is designed depending on the consumed peak power. If the system has accumulators, the photovoltaic panels number is assessed depending on the consumed average power. The inverter is still chosen depending on the consumed peak power.

Table 1. Technical requirements for a conversion and storage system

Joining process	Average power [kW]	Peak power [kVA]	Number of panels PV	In termit tent reg. DA %	Accumula-tors capacity [Ah]	Number PV/ DA (unfav.)	Applicable
Manual metal arc welding (covered electrodes)	5.43	5.5	24	80 (10) (35)	5470 683	16 2 (32)	Yes
Gas metal arc welding (MIG/MAG)	6.76	10	50	80 (40)	9244	50 (67)	No
Soldering with non-ferrous alloys	0.8	2.2	11	100 (40)	1504	5 (15)	Yes
Ultrasonic welding	1.22	6.08	6 (15)	40	2051	6 (20)	Yes
Stored energy welding	0.19	4	20	70 (80)	-	4 (11)	Yes
Stud welding	1.25	4	5 20	80	1713	5 (21)	Limited
Laser welding, cutting and marking	2.11	7	11 (35)	80	2880	9 (29)	Yes
Friction stir welding (FSW)	1.9	11.4 (29.8)	10 (57)	100 (40) (80)	1298	10 (13) (26)	Yes
Resistance spot welding	4	10	50	80 (80)	5470	16 (54)	No
Plastic foils welding	1.1	1.1	6	100 (80)	1504	6 (15)	Yes
Polyethylene tubes welding	3.26	4	17	100 (40)	2229	7 (22)	Yes
Plasma cutting and delivering	5.55	12	28	100 (37)	16 410	28 (74)	No
(*) under unfavorable atmospheric conditions							

4.2. Technical data for the conversion system

For designing and realizing a conversion system, the following data are necessary: the total energy amount produced in a year by a photovoltaic module in the established location, the maximal power received from the sun during a day and the dayly energy balance.

4.3. Technical characteristics of a conversion and storage system, applicable to joining equipments

The basic elements of a conversion system are the photovoltaic panels. The main technical characteristics of these are: maximal power 120... 200W; rated voltage 12 V or 24 V; sizes 1310mm x 675mm x 35mm (±2mm); withstanding to hail of 28 mm; impact speed 90 km/h; maximal effort on the surface 2400 N/mm^2; maximal wind speed 200 km/h [11]-[14].

4.4. Components of an autonomous conversion system, with photovoltaic panels

A conversion system with minimal outfit and reduced cost of the investment is presented in the Figure 2. It consists of four photovoltaic panels, a charger, accumulators having the total capacity of 530Ah, a 12VDC / 230VAC invertor with the apparent power of min. 3 kVA. It is able to supply a source for manual metal arc welding with covered electrodes, rated 3kVA, 160 A

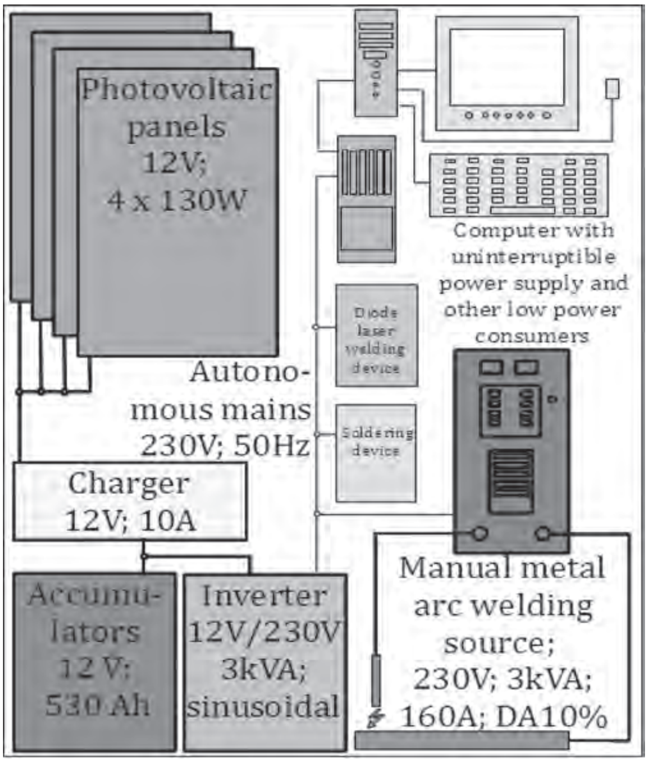

Figure 2. Solar energy conversion system for joining equipments

welding current, by DA = 10...35 %, for on-site repairing jobs and casual applications. Other consumers may also be plugged in: a soldering iron of 0.1...0.3 kW, a diode laser welding device of 0.1...0.4 kW; a computer with an uninterruptible power source of 0.2...0.5 kW; various electronic sets.

5. Monitoring system for assessing the electric energy consumption

A monitoring system was used for measuring the consumed current of some welding equipments. It was firstly applied at the equipment for friction stir welding (FSW).

The monitoring system is presented in the Figure 3, having the following components: travel table with the motor for horizonal movement (1); mechanism and motor for vertical

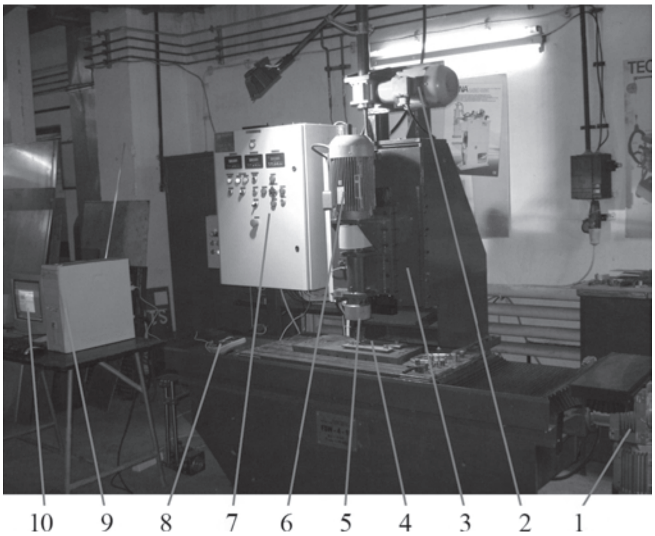

Figure 3. Monitoring system for assessing the electric energy consumption

movement (2); assembly of the equipment type FSW-4-10 (3); plates to be welded (4); tool for the FSW process (5); motor for rotating the tool (6); control desk and electric board of the equipment (7); multimeter type UT70B (8); computer PC (9) for data acquisition, respectively for recording the measuring

Figure 4. Multimeter with data acquisition

Figure 5. Indicator dial of the virtual measuring instrument

results, monitor of the computer (10). In the Figure 4 the electronic multimeter type UT70B is shown, with RS 232 interface for data acquisition on the computer, where the measured extents of the current are recorded in the sampling moments. In Figure 5 there is the indicator dial of the virtual instrument presented on the computer monitor by the multimeter software. On the monitor screen a real time diagram of the current measured on one phase of a motor of the FSW equipment is also shown.

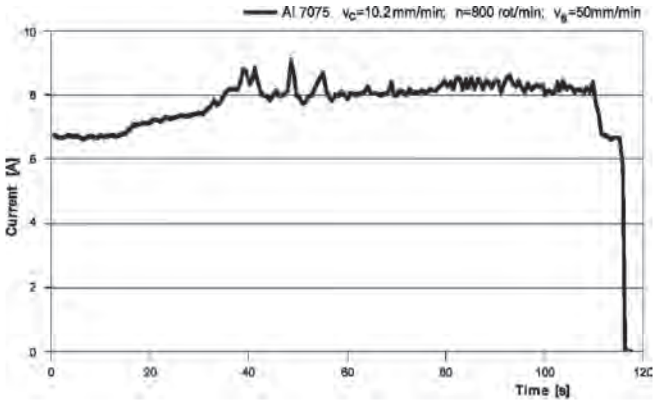

Figure 6. A graphic record of a variation of the current by the horizontal movement motor of the FSW equipment

The measured and recorded data can be presented as graph charts, for analysing them, in the stage of the technology elaboration, respectively for confirming the applied welding conditions, according to the requirements of the quality management system. Such a graphic diagram of the variation of a motor current is shown in the Figure 6.

6. Other sources of regenerative energy

For the direct use of the thermal energy produced by the sun, furnaces are manufactured, with radiation concentrators, such as parabolic mirrors of 0.85 – 10 m^2 or Fresnel lenses of 0.5 – 2 m^2. They produce 150...500ºC temperature and the period of the joining process is 2.0... 20 seconds. An application of solar energy with concentrators to welding the aluminium alloy 7075 was experimented on the solar furnace CNRS of Odeillo, France [15].

Some applications of hybrid photovoltaic and thermal panels are also presented [16].

Other applicable sources of regenerative energy are wind and hydro-generators rated at 4 - 10 kW.

Solar thermal panels of 4 - 10 kW for hot water supply and heating are utilized for realizing the working conditions, according to the requirements of the standards for the environment protection, labour safety and occupational health, in workshops and construction sites in remote areas.

7. Technical-economical analysis of a conversion system

The expenses for electric energy of a certain consumer can be reduced or even annulled, if the output power of the conversion system with photovoltaic panels and its configuration are chosen depending on the necessary energy extent per year of the consumer and related to the amount of the sunny hours each year, in that location, according to the criteria established in the previous chapters.

The mostly applied cost for producing electric energy on photovoltaic panels is 0.21 Euro / kWh. The recover period of the investment for realizing a conversion system based on photovoltaic panels is 8...25 years.

8. Conclusions

1. The joining and allied processes where the application of some solar energy conversion systems is possible, under the condition that the level of the necessary average power is at most 3...4kVA, are the following: manual metal arc welding with covered electrodes; soldering with non-ferrous alloys; ultrasonic welding; stored energy welding; stud welding; laser welding, cutting and marking; friction stir welding (FSW); plastic foils welding; polyethylene tubes welding; thermal oxygen-gas cutting and delivering.

2. The application of conversion systems to other joining and allied processes is difficult, because of the high extent of the necessary average power: gas metal arc welding (MIG/MAG); resistance spot welding; plasma cutting and delivering; water-jet abrasive cutting.

3. The benefits obtained by the protection of the environment are very important.

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