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Design of Resistance Spot Welding System using Integral Switching Cycle Control Technique

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Abstract**—** The process of combining metal of similar composition by heating at suitable temperature with or without pressure and application of filler material is known as Welding. Resistance Spot Welding (RSW) is defined as a process which requires simultaneous application of high electrical current and appropriate pressure over short periods in order to keep the molten material inside the weld zone. Values of these parameters are varied in function of the characteristics of the materials to be welded. The application of the electrical current carrying two copper electrodes brought in contact with the welded parts while the required pressure is applied by means of pneumatic or hydraulic systems. This paper presents a novel design of resistance welding system using Integral Switching Cycle Control Technique used for performing a welding process. The paper is discussed about two aspects. First, a brief introduction about welding, methods of welding control and electronic control used in resistance welding. Secondly, the critical factors in design of a welding process are dealt along with the principle of the welding process. Following this, the introduction to the design of control scheme employed with the basic block diagram of welding system and its functioning is presented.

Keywords*- Burst Firing, Heating Application, Integral Switching Cycle Control (ISCC), Resistance Spot Welding (RSW).*

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I. INTRODUCTION

Welding is the process of combining two or more metal pieces with the application of heat and pressure [1]. In this process two metal parts are heated at a plastic state and then joined by applying external force is known as plastic welding. Two metal parts to be joined together are heated up-to molten state and then allowed to solidity using a localized homogeneous union of the two is known as Fusion Welding. Resistance welding uses the concept of heat generated due to the current flowing through a metallic substance itself. The heat energy generated is large enough to bond two work-pieces together. Automated resistance welding machines use micro-controller based control systems to regulate and ensure consistent welding [2]. The amount of heat produced is determined by the relationship between the electrical resistance and current being passed for the time current is allowed to flow.

The heat produced is proportional to the square of the current multiplied by the resistance and multiplied by the time interval [3]. The resistance values are commonly very low and the time cycles are required to be very short [4]. This results in the need for exceptionally high welding currents in the range of 20 KA. Equipments capable of delivering such high currents for closely controlled tiny time is naturally expensive and the resistance welding processes are therefore suitable only for mass production applications where the expenses are justified.

The main advantages [5], [6] of resistance welding are it is appropriate for mass production, accurate control, no need for filler metal, fluxes, ability to weld dissimilar metals and negligible metal losses. Varieties of resistance welding are unanimously known as spot welding, gun welding, shot welding, flash welding and seam welding and projection welding. In all of these, fundamental operations remain same but the preparation of metal and the construction of machines may be different [7].

The process finds extensive use in welding of Mild Steel, Stainless Steel, heat resisting alloys, Aluminum, high Nickel alloys, Copper alloys, and reactive metals like Titanium. Dissimilar metal combinations can also be welded. Automotive accessories, Home and Kitchen appliances, computer and electronics parts and Industries products are extensively welded by RSW. Normally this process is used for work thickness of up to 3 mm but steel up to 6 mm thick are occasionally welded and in rare application the process is reported have been used for plate thickness up to 22 mm. [8].

II. RESISTANCE SPOT WELDING

2.1 Power Supply for RSW

The welding current for resistance welding may be altered by changing the output voltage of a welding transformer. In simple equipment, a large number of taps are provided in the transformer which enables a coarse control of welding current. The welding heat input is regulated by a closer control of welding time. In expensive units or when large current is required, switching is performed by SCR or IGBT. These are Power Semiconductor Devices (PSD). When a control voltage is supplied to PSD, current can flow through devices. By connecting the PSD circuit to an accurate timer, a very precise control of welding time can be achieved. Resistance welding power supplies are rated in terms of power (KVA) available. The KVA rating specifies the power that can be drawn for thirty seconds out of each minute (a duty cycle of 50 %), thus allowing for cooling period. For welding metals with high thermal conductivity and low electrical resistance such as aluminum, three phase transformers with a bank of PSD are required. High power rating (about 100 KVA) may be employed.

2.2 Method of controlling RSW

Phase Angle Control (PAC): The principle of phase shift is used for varying the welding current. This is done where; slow cooling of the welds is required for the metallurgical reasons. A complete sequence of currents may be automatically controlled to affect the welding process and heat treatment of welds. In typical alloys where control of thermal cycles is essential to produce satisfactory welds, this method is implemented.

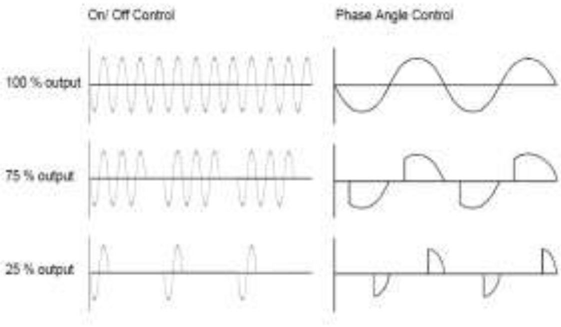

Fig. 1. Comparison of Phase Angle Control and Integral Cycle Control

Integral Cycle Control (ICC): It works on the principle [9] of on - off control, when the controller is in the ON (N) mode, a number of current cycles are controlled. The number of current cycles passed conjugatively; determines the amount of current that flows through the electrodes. This is the time when the welding takes place. As shown in Fig. 2 no current passes through the electrodes when the controller is OFF (M).

Eventually it happens more to the operation of resistance welding machines than the control of the electric current. With the help of pneumatic circuits supplied with compressed air, mechanical handling, positioning, and clamping of the work piece and the application of the electrical pressure are accomplished. It is a common practice to actuate the timer for the air pressure once it is exceeded a value which ensures adequate contact pressure between two electrodes.

Complete automation of the resistance welding process may be achieved by this design. This is accomplished by accepting various process inputs from the user and after due process, controlling various parameters like the current, no of cycle, weld count, etc., This is achieved by using a microcontroller, which will attain data from the user and process it to generate suitable control signals as and when required for welding process. The use of a personal computer makes the operation extremely fast, reliable and flexible. At this juncture, the most important parameter to be monitored and controlled is the primary welding current. For constant current control method, an adaptive algorithm takes care of the present and past values, to predict the firing angles of thyristor in the subsequent cycle, to ensure the pre-set value of the current is sustained. Various other parameters like the weld count, job count, number of on cycle, etc., are also monitored. This is done by using a micro-controller which will look after all the processes parameters with minimum of supervision.

2.3 Integral Switching Cycle Control:

Fig. 2(a) describes the waveform conventional ICC and proposed switching pattern ISCC. Proposed technique is different from the conventional in the regard of the off-time despite of changing the power output it will improve the harmonic spectrum as described in Fig.2 (b).

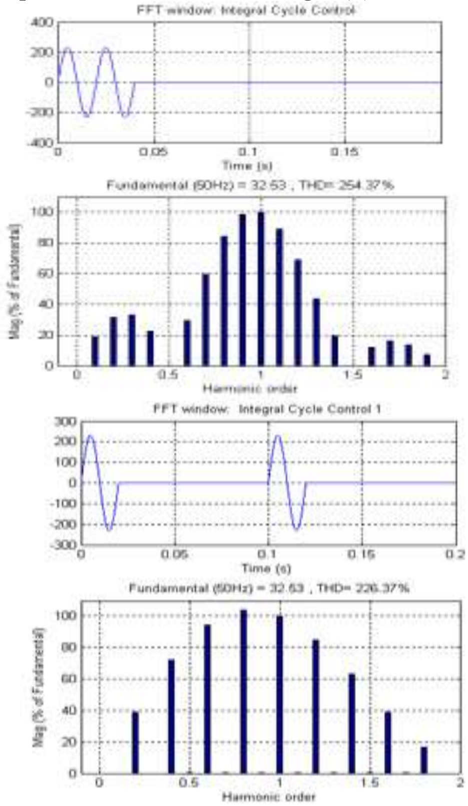

Fig.2 Waveform and harmonic profile of ICC and ICS

Fig. 3 describes the variation of THD with duty cycle (D = N / N+ M) for the both method. As seen from the graph for the high duty cycle of D =0.8 THD decreased by 13.91 % while this method is useful even for low duty cycle D = 0.2 because reduction in THD is 28 %. This is help not for the RSW but it may be employed for the heating application. Thus, this method proves more reliable for the low duty cycle than Phase Control Switching (PCS).

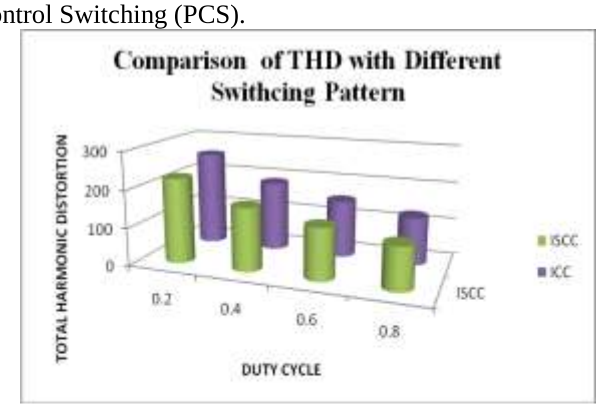

Fig. 3. Comparison of THD with ICC and ISCC

2.4 Critical Factor in RSW

Current, voltages, power, resistance, transmitting force, transformer specifications, current density, throat dimensions and the electrodes are the critical factors involved in welding.

The current is generally measured in KA. The welding time varies from 3 to 120 cycles of current. Table 1 shows the variation of sheet thickness, electrode tip diameter, minimum electrode force, welding current and weld time. [10]

TABLE 1
MACHINE SETTINGS FOR SPOT WELDING MILD STEEL SHEET

Sheet Thickness (mm)	Electrode Tip Diameter (mm)	Min. Electrode Force (N)	Welding Current (KA)	Weld Time Cycles
0.3	3	540	6	4
0.55	4	845	7	6
0.9	4.5	1200	8	10
1.2	5.5	1670	9	12
1.6	6	2230	10	16
2.0	7	2780	11	20
2.6	8	3340	12	25
3.2	8.5	4000	14	30

A resistance weld cannot be made unless there is a sufficient weld current. If current is the amount of electricity flowing, then voltage is the pressure or force that's causing the flow. Power is voltage measured by current and is in watts or KVA. This means the amount of current flowing times the pressure that's causing it to flow equals the amount of power generated. Resistance is the opposition to flow of current. Since R to I is what generates the heat in the work piece, it is critically important that the area with the greatest resistance be at the interface between the two pats being joined. The heat is where the resistance is, and the resistance is where the heat will be.
The step-down transformer used is of high rating is used as it should be capable of supplying amount of high (1000A to 10000 A) weld current. Thyrite resistor R is placed across the primary winding to protect the transformer against transient produced due to sudden make and brake of the current.
The amount of force needed to make a good weld varies, depending on the type of metal being welded and other factors discussed in [11] but a general figure would be about 540 to 8900 N.
Current density describes how much current is being delivered to a specific area. It describes the concentration of the current in a small area of the work piece. Throat dimensions are an important factor for current determination.
Electrodes play a very important role in the successful operation of a spot welding machine. They must conduct the welding current to the work without overheating. They must at the same time conduct heat away from the surface of the sheet being welded and they must apply pressure to the work without deforming. The diameter of the electrode is calculated by the equation 1.

$$de = (0.1 + 2 * t) \text{ mm} \qquad (1)$$

Where t = thickness of plate and de= diameter of the electrode. Generally mild steel up to 10 mm, aluminum up to 6 mm and copper up to 1.5 mm is welded using RSW. [9]

III. PRINCIPLE OF RSW

Ohm's law states that, Voltage = Current X Resistance.

$$V= I * R \qquad (2)$$

Joules law states that, Heat = V * I * t

$$Heat = V * I * t = I^2 R * t. \qquad (3)$$

Where t = time for which current flows.
Basically, the heat energy required for welding depends on the square of the welding current flowing between the two electrodes and on the resistance offered to this current between the two electrodes. The resistance taken into account contains the resistance of the welding electrodes and the resistance of the jobs to be welded together.
The welding process variable include the weld current, squeeze time, weld time, hold time, electrode force, design of the electrode and the work piece material as is shown below in Fig. 4 and typical resistance weld is separated down into several distinct periods, is also shown.

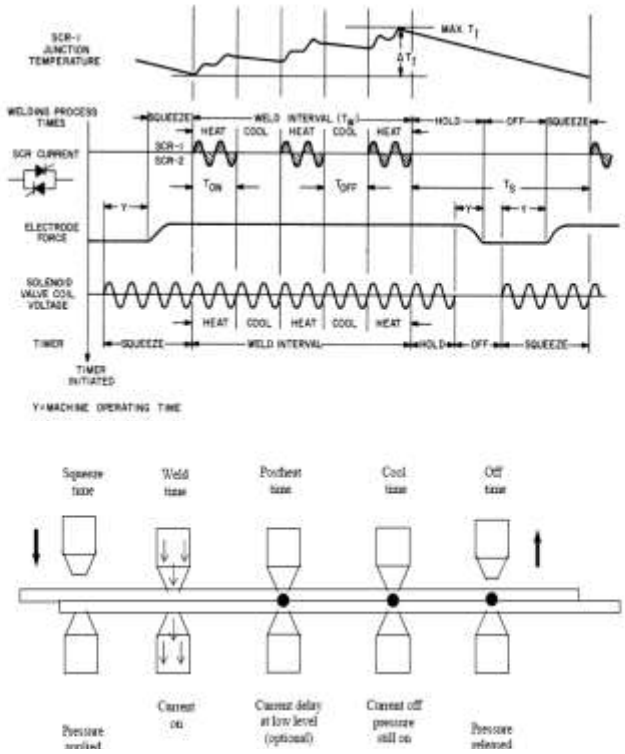

Fig. 4. Different time Phases of Spot Welding cycle and the weld cycle of the welding process

When the weld heads (electrodes) come together and build up to a specified amount of force before the current is fired; is known as squeeze time. When the current is actually passing through the work pieces, this is when the metals are being heated enough to melt and fuse together to form a weld nugget; is identified as weld time. Throughout the hold time, the electrode force is still applied, even after the weld current has ceased. In this period, the weld nugget cools and the metals are forged under the force of the electrodes. The ongoing electrode force helps keep the weld intact until it solidifies, cools and the weld nugget reach its maximum strength. The time period span between the release of the electrodes from the work to the start of the next weld cycle is known as the off-time of the machine [2].

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IV. ELECTRONICS CONTROL OF RSW

This section describes the some of the important Electronic Welding controls methodology generally employed in the RSW. The basic type of the electronic timer is described in the [12].

The Sequence Timer: This is more elaborate electronic circuit which includes:

Squeeze time – It is the time that elapsed between the electrode pressure first applied on the work and the initial application on the current.

Weld time – It is the time for which the welding current, expressed in the cycle, actually flows to melt the metal at the interface.

Hold Time – It is the time during which the pressure is kept applied at the point of the welding after the welding current has ceased to flow.

Off Time – After the weld is perfectly hardened, the time that elapses before the electrodes reclose, if the welding machine is still energized, is OFF time. [12]

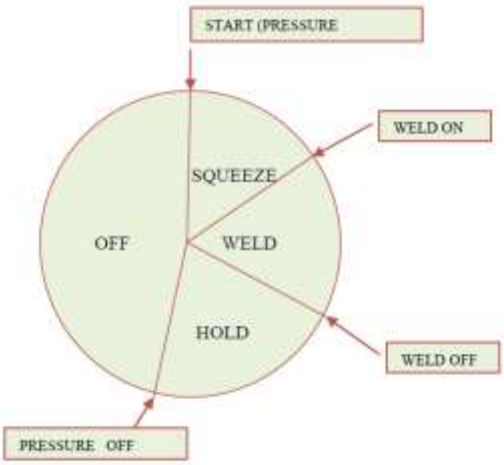

Fig. 5 Sequence of Operation of Welding Timer

Pulsation Timer: This is a timer which controls the number of cycles for which the welding current flows and the number of cycles for which it is allowed. It is a variation of spot welding. In pulsation welding, the welding current flows intermediately unlike spot welding in which current flows continuously until the weld is formed. This intermittent flow of current permits the water-cooled electrodes to remove heat from the surfaces of the materials and thereby cause higher temperature gradient near the weld. This method is popularly used for pieces thicker than 1 cm.

V. BLOCK DIAGRAM OF PROPOSED SYSTEM

In [13] the authors have also published the way to perform Resistance Spot Welding Using PLC. As the number of parameters are more like the user inputs the welding current, no. of cycle required for squeeze, weld and hold cycles and the job count it works very fine, but the in the proposed technique because of disadvantage of ICC [14] authors proposed ISCC technique using micro controller.

ISCC has been simulated, variation in output voltage due to variation in duty cycle and phase angle is observed and its graph is drawn from various reading of duty cycle and phase angle and it is found that as duty cycle(D) increases output voltage increases and as firing angle (α) increases output voltage decreases. THD for different duty cycle and phase angle is found using FFT Analysis and it is found that Value of THD is maximum around the firing angle $\alpha = 160^\circ$ to 170°. Using ISCC method higher order harmonics can be removed and smooth voltage control is possible which the limitations of PCS and ICC method are respectively but its cost will be relatively higher than both these method [15].

The micro-controller reads this data and calculates the approximate number of cycle required to obtain the desired welding current. A control voltage corresponding to this number of cycle is applied to the Pulse Generator and Zero Crossing Detector (PGZCD) circuit through a DAC. To trigger the high power anti-parallel thyristor in the main welding transformer, PGZCD is used.

This PGZCD identifies the zero crossing of the ac line voltage through a stepped down transformer and this zero crossing is indicated to the micro-controller through a port line. The micro-controller coordinates the firing of the thyristor with the zero crossing in every half cycle.

The firing of the thyristor takes place for the number of cycles according to applied input. During this time, the micro-controller receives feedback about the actual welding current to be made available through an ADC. Suitable action is taken to ensure that the actual welding current is very adjacent to the desired welding current. Once a particular job has been welded, the microcontroller displays the relevant information, which is essential to the user.

This includes the actual welding current and the number of jobs completed. If during the welding process, an error occurs, facility is made to indicate the occurrence of the error. A 12 V power supply for the PGZCD and DAC, 15V supply for the ADC, 5V power supply for the rest of the circuit is designed and incorporated in the overall system design. The design also includes provisions to store an entire schedule for future use. This helps in avoiding mistakes and eliminates the need to re-enter all the data

VI. SIMULATION OF PROPOSED SYSTEM

Simulation of proposed technique using MATLAB Simulink has been carried out by the authors and results are discussed.
Fig.7. shows the simulation result for ISCC for the circuit topology discussed in block diagram [16].

Simulation is carried out in MATLAB R2006 with simulation parameter configuration of fixed step type ODE 4 type (Runge-Kutta) with unconstrained Periodic Sample time of fixed step size of 1e-6.

By doing MATLAB simulation the result of the pulse generation for the both power devices, output voltage of the

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transformer and output current and output of the solenoid valve have been generated as shown in Fig. 6 (b).
The expanded view of the one welding cycle is described in the Fig. 8

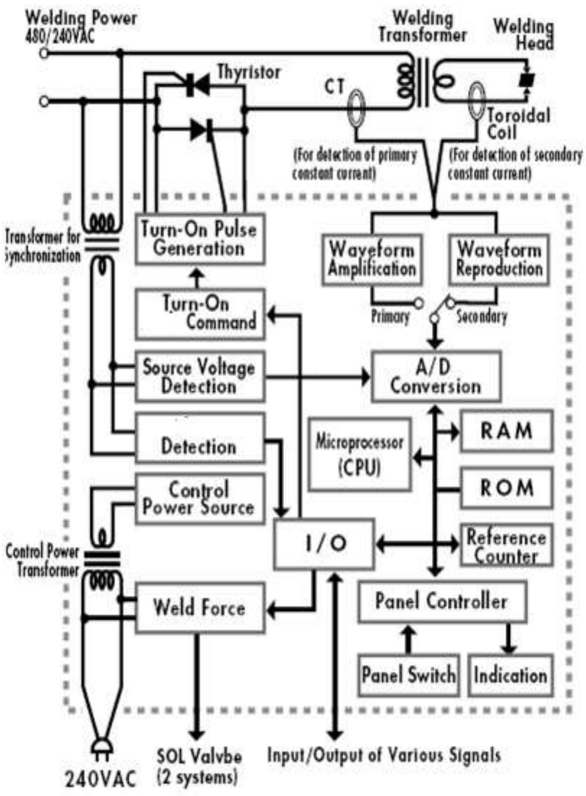
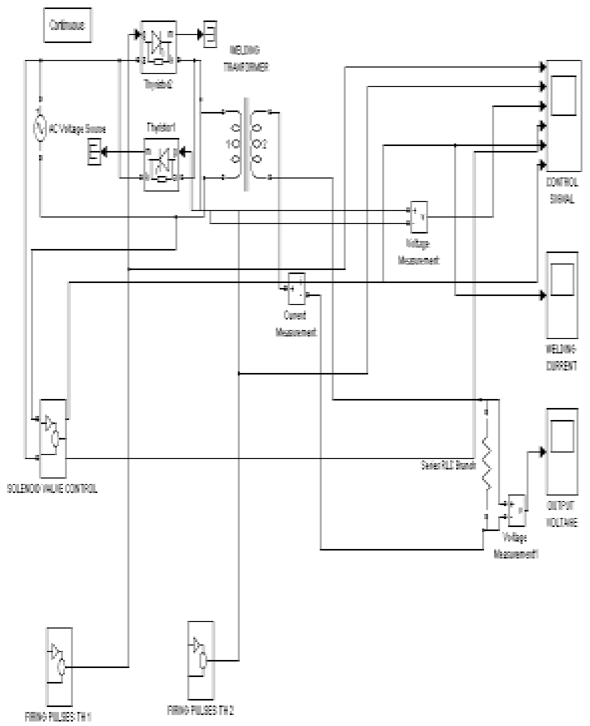


Fig. 6 Block Diagram of the proposed control strategy.

In the simulation the control signal for the both power devices and solenoid is of 12 V. The output voltage rating of the transformer is 12 V and current is 4000 A.



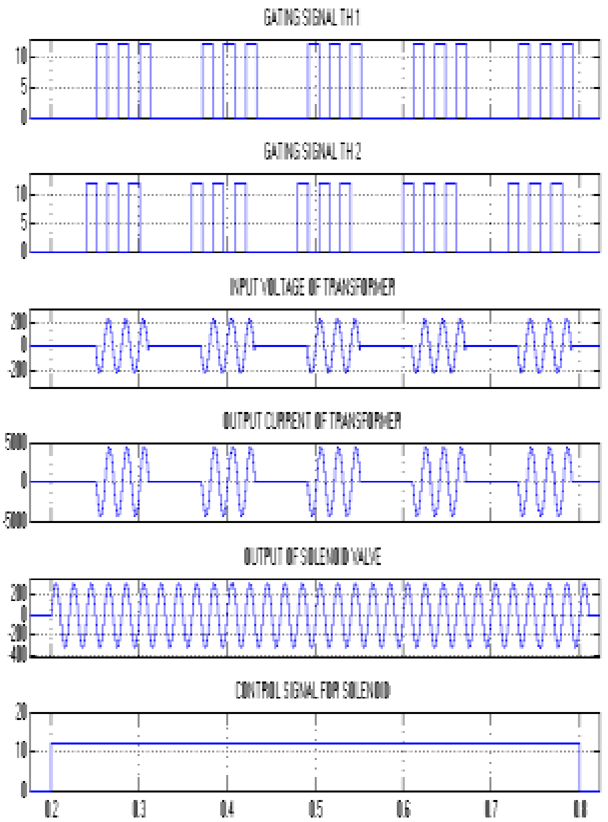


Fig.7.MATLAB Simulation Diagram for RSW and Simulated Waveform of RSW.

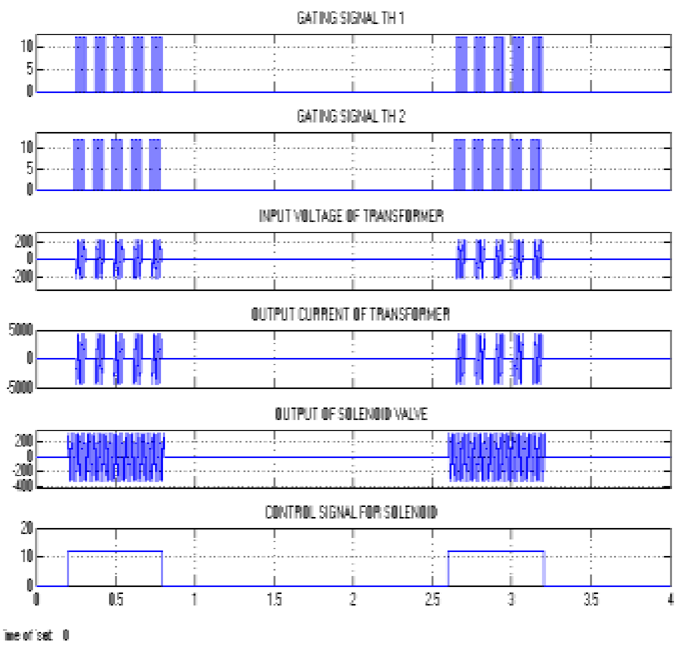


Fig. 8. Expanded view of the one welding cycle.

VII. CONCLUSION

In this paper, authors have investigated the Integral Cycle Control for the Resistance Spot Welding application. This method is simple and injects fewer harmonics than any other method. As discussed in the paper for the high duty cycle of (D =0.8) THD decreased by 13.91 % while this method is

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useful even for low duty cycle (D = 0.2) because reduction in THD is 28 %. Thus, this method proves more reliable for the low duty cycle than Phase Control Switching (PCS).

In addition, informal enhanced gain as well as high reliability of Resistance Spot Welding might be obtained. The problem with ICC is it will control only the discrete value of power while PCS method will have more THD as compared with ICC. In this paper author have proposed Integral Switching Cycle Control technique for Resistance Spot Welding Application. To prove the performance of proposed scheme some simulation results have been presented.

ISCC has been simulated, variation in output voltage due to variation in duty cycle and phase angle is observed and its graph is drawn from various reading of duty cycle and phase angle and it is found that as duty cycle(D) increases output voltage increases and as firing angle (α) increases output voltage decreases. THD for different duty cycle and phase angle is found using FFT Analysis and it is found that Value of THD is maximum around the firing angle $\alpha = 160^\circ$ to 170°. Using ISCC method higher order harmonics can be removed and smooth voltage control is possible which the limitations of PCS and ICC method are respectively but its cost will be relatively higher than both these methods. The experimental study for the proposed power control system will be specified later.

REFERENCES

[1] David Mintz, John T. Wen "Process Monitoring and Control for Robotic Resistive Spot Welding" 4th IEEE conference on Control Application, July 1995 pp. 1126-27

[2] T. C. Manjunath, S. Janardhan, N.S. Kabul, "Simulation, Design, Implementation and Control Welding process using microcontroller" in IDP in System Control engineering system Lab, IITB, ACRE Building, Mumbai.

[3] Jun Seo-Moon, Gyu-Sik Kim, Jun Seo-Moon, Gyu-Sik Kim "Power Control of Resistance Spot Welding System with High Dynamic Performance" IEEE Journal of Ind. Elect. Vol. 45, No. 3, May 1995 pp 845-849.

[4] Robert W. Messler, Jr., Min Jou and C. James Li "An Intelligent Control System for Resistance Spot Welding Using a Neural Network and Fuzzy Logic", IEEE Trans. Ind. App. May 1995.

[5] Justin Shriver, Huei Peng, S.Jack Hu "Control of Resistance Spot Welding" Proceedings of the American Control Conference San Diego, California June 1999 pp.187 – 191.

[6] Ramavatar Singh Rathore, Dr. Anil Kumar Sharma and Hirendra Kr. Dubey. "Design, PLC Based PID Implementation in Process Control of Temperature Flow and Level." International Journal of Advanced Research in Engineering and Technology, 6(1), 2015, pp. 19 - 27.

[7] B. D. Gurav and S.D. Ambekar. "Optimization of the Welding Parameters in Resistance Spot Welding." International Journal of Mechanical Engineering and Technology, 4(5), 2015, pp. 31-36

[8] Roger B. Hirsh "Some Lesser Known Uses of Resistance Welding Equipment" Practical Welding Today, Issue May – April 2001 pp 20-25.

[9] V. M. Radhakrishanan, Welding Technology and Design, New Age International Publisher (2000) Ch.1 pp. 23 – 26

[10] N. D. Mehta, B. B. Kadam, "Design, Simulation, Implementation and Control of Low Cost Solid State Power Controller" in International Journal of Engineering Technology, Management and Applied Sciences, (IJETMAS) August – 2015, Vol. - 3, Issue -8, pp. 130- 134.

[11] Jai P. Agrawal, "Power Electronics Systems – Theory and Design" Pearson Education P. Ltd. (2001) Ch 10 pp.355-57

[12] H Tang, W Hou and S J Hu "Forging force in Resistance Spot Welding" Proc Inst. Mech. Engrs Vol 216 Part B: J Engineering Manufacture July 2002 pp 957 -968.

[13] N. D. Mehta, Dr. D. K. Bhatt, "Implementation and Control of Integral Cycle Controller for Resistance Spot Welding" International Journal of Research in Engineering and Technology IJRET: August-2015 Volume: 04 Issue: 08, pp. 417 -421 .

[14] N. D. Mehta, Dr. D. K. Bhatt, "Design, Simulation, Implementation and Control of PLC Based Integral Cycle Controller for Resistance Spot Welding Application" International Journal of Advanced Research in Engineering and Technology (IJARET) Volume 6, Issue 8, Aug 2015, pp. 57-68.

[15] N. D. Mehta, Dr. D. K. Bhatt, "The Effect of Switching Strategies on Power Quality for Integral Cycle Controller in Heating Application" International Journal for Research in Emerging Science and Technology, IJREST: Oct-2015 Volume-2, Issue-10, pp.12-18.

[16] N.R. Suchak, A.D. Joshi, N.D. Mehta, "Design and Simulation of Novel Integral Switching Cycle Control for Heating Load" International Conference on Innovative Science and Engineering Technology – 2011, ICISET – 2011, at V. V.P. Rajkot 8 -9th April 2011 pp. 600-603.