Qualitative Study of Status of Indigenous Arc Welding Equipments in India

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ABSTRACT

Energy contributes to less than 2% of arc welding process cost. However, the way energy is controlled dynamically in the weld gap, its role becomes catalytic in nature to the whole process, beyond weld gap. In open or close loop, manual, semi-automatic or automatic mode of operation, power source is lone actuating element in the whole arc welding process influencing not only output characteristics, but also on other input elements. Welding equipment together with efficient method converts arc welding process load as efficient in electrical energy domain. Matching of power source and equipment is essential. However, in many developing countries in the world the matching is yet to take place causing a lot of all round concerns, wastage and productivity are a few of them. Concern is, India being a large size large growing country, also falls in that category. Indian process is heavily inclined to SMAW process using old fashioned equipments. Among population of arc welding equipments, CC power sources are dominant. This makes, ironically enough, data generation and its analysis easy. As it is difficult to have direct and correct statistical data, this article takes the route of qualitative analysis on the status of arc welding equipments in India.

INTRODUCTION

Manufacturing contributes significantly in gross domestic product (GDP) of a country. More than 50% [1] of manufacturing activity associates welding and joining of metal as one of the processes. A well established efficient welding technology base is vital to efficiently handle manufacturing growth for any country. Its growth co-relates to productivity. Gain in productivity largely depends on technology base of welding. At present, India is on the upsurge of large growth in infrastructure, its technological base in arc welding to support its growth is more vital. Research, development and manufacturing of arc welding equipment are vital to create capability for the process.

Arc welding process is more than 130 years old. It is a versatile and cost effective process of joining metals. Unlike other contemporary fields such as electric motor with drives or even more recent fields such as power controllers for information technology equipments, arc welding is still evolving. One of the reasons is that the origin of control and actuation of electrical parameters of arc gap [2] is indirectly coupled to the output process parameters as shown in Fig. 1, and detailed [20] in Fig. 2. Coupling is improved through right feedback and proper actuation as shown in Fig. 3. However, the link is complex due to absence of cost effective feedback signals of high temperature molten pool. Actuation is always through welding equipment. Majority of welding applications operate in open loop as shown in Fig. 1. Only notable signals available for feedback are arc voltage V_{arc} and welding current I_a.

Arrangement in Fig. 1 does not guarantee actual quality engineering parameters of the process such as

i) Weld bead geometry
ii) Micro-structure and material properties
iii) Mechanical strength of joint
iv) Residual stress and distortion, etc

In order to have better control on parameters [2] mentioned above, following parameters (both are temperature dependent), in excess of V_{arc} and I_a, need to be controlled

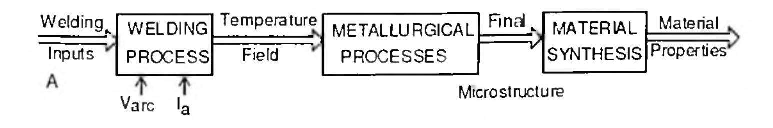

Fig. 1 : Arc welding process in open loop configuration

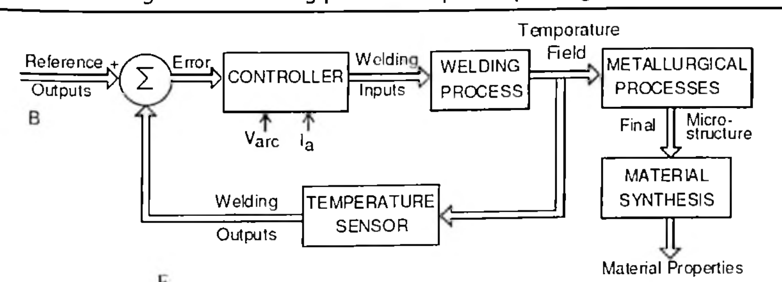

Fig. 3 : Arc welding process in closed loop configuration

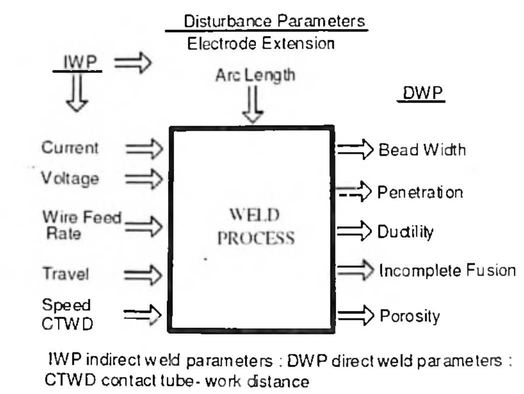

Fig. 2 : GMAW input/output relationship

i) Heat effected zone

ii) Centre line cooling rate, etc

In order to achieve the desired quality of welding joint, the process need to be automated through outer temperature control loop (Fig. 3). The outer loop expects smooth functioning of the inner loop i.e. of welding equipment. SMAW operates exclusively as per Fig. 1 and it lacks automation flexibility. It does not entertain any extra loop for control. Therefore, SMAW may not be the ideal choice to achieve better quality engineering parameters of joint. On the other hand, both GMAW and GTAW are suitable for automation. Additionally, GMAW is preferred as this process is much more productive and suitable for all-metal-all-position welding. Ongoing research is mostly GMAW-centric. Initially till 1960s, due to lack of suitable components for control and power, getting a proper power source for arc welding was major concern. Equipments were crude, bulky and inefficient and lacked much in control features such as speed of response etc. Arc welding process, therefore, evolved around finding optimized method for arc welding for process efficiency. GMAW and its derivates have been found most suitable among all. Most literatures of research are centred around how GMAW and its derivatives be made globally reachable to common users. If it happens, it would reduce process diversity, achieves better productivity with quality, reduce environmental concerns, and it can reduce involvement of human welders. The input-output diagram of a GMAW (Fig. 2) process with automatic process control [2] is shown in Fig. 3. This particular era of finding the most suitable welding method could be regarded as most important phase of research in arc welding. Virtually all developed nations were in sync in that development phase. India's contribution, in that period, was negligible. Its role was as a user of technology. India's steel consumption was less till 1980s and its arc welding process was dominated by SMAW. It is still the same. At present, there is a surge in steel consumption. Presumbly, it would reflect in arc welding process as well. This article discusses the impact of prevailing arc welding process of India and looks for the journey for future.

INDIAN PROCESS IS DOMINATED BY SMAW

The amount of steel being consumed gives an indication about the status of manufacturing industry of a country. Arc welding process is, however, directly linked to annual consumption of steel. As a general rule [3], 0.5% of total steel being consumed is required to be deposited as weld metal. India's per capita consumption of steel is still poor. China consumed 489 million ton [4] of steel in 2007 (Table I) i.e. 39 kg / person /year, whereas an Indian on an average consumes only 47 kg / person / year. Though, both countries have high growth rate in steel consumption, India's growth rate is much higher, presumably because its present per capita consumption is much less. Table I shows comparative chart of crude steel produced [4] by a few countries in 2007 where China was dominant.

Table II [3] shows the approximated trend of consumption of welding method specific consumables in Indian arc welding process. It, even today, is heavily dominated by SMAW (77%). However, it indicates a slow and as if reluctant shift towards GMAW. It apparently indicates that the sense of productivity and energy efficiency [5] yet to pervade minds of Indian users. There is broad divide among user base in India – from a few medium to large size organized customers to existence of large number of small-scale users. Many of them possess single

Table I : Crude Steel Production in year 2007 (million ton)									
World	India	China	Japan	USA	Russia	Germany	Ukraine	Brazil	Italy
1343.5	53	489	120.2	97.2	72.2	48.5	42.8	33.5	32

Table II : Current share and projected share of welding process

Year	Parameter	SMAW	GMAW	SAW	GTAW & Others	Total
2003 - 2004	Weld Metal	114000	25480	10650	1520	152000
	Electrode/wires	182400	28420	11700	1670	224190
2004 - 2005	Weld Metal	119880	29160	11340	1620	162000
	Electrode/Wires	191810	32080	12470	1780	238140
2005 - 2006	Weld Metal	125850	32760	12070	1720	172400
	Electrode/Wires	201360	36040	13280	1980	252570
2006 - 2007	Weld Metal	132190	36720	12850	1840	183600
	Electrode/Wires	211500	40390	14130	2020	268040
2007 - 2008	Weld Metal	138820	41050	13680	1950	195500
	Electrode/Wires	222110	45150	15050	2140	284450
2008 - 2009	Weld Metal	145600	45760	14560	2080	208000
	Electrode/Wires	232960	50340	16020	2290	301610
2009 - 2010	Weld Metal	153060	51010	15530	2200	221800
	Electrode/Wires	244900	56110	17080	2420	320510
2010 - 2011	Weld Metal	160620	56690	16530	2360	236200
	Electrode/Wires	256990	62360	18180	2600	340130
2011 - 2012	Weld Metal	168870	62900	17610	2520	251600
	Electrode/Wires	269710	69190	19370	2770	361040
2012 - 2013	Weld Metal	176820	69650	18750	2680	267900
	Electrode/Wires	282910	76610	20630	2950	383100

equipment each, mostly welding transformer. It is extremely difficult to have data of such users. However, unfortunately though, both sectors prefer to use mostly SMAW process. Flexibility in power sources (DC & AC both can be used), low capital and running cost are some reasons for adopting SMAW process. However, energy and process efficiency parameters are poor in SMAW. The process cannot be automated for productivity. It also generates more fumes and particulate matters. Welders feel discomfort to weld longer time holding hot long electrode. The deposition rate is restricted to around 2.5kg / hr [6]. Moreover, there is waste of hot metal in each electrode while being replaced, and only 65% of consumables are converted into weld metal. Power source is still energized during electrode change.

How it translates to share of equipments

Certain applications for high quality joint for stainless steel welding use specific GTAW equipment. Otherwise many SMAW equipments have built-in GTAW facility. Use of GTAW process is gradually reducing. The operating duty factor (15%) of SMAW equipment is poor. On the other hand, GMAW even in equipments in semi-automatic mode possess better operating duty factor (3:1) with respect to SMAW counterpart. Moreover, GMAW [6] have better weld metal deposition rate per Amp (1.5:1). GMAW equipments in automated applications have much better operating duty cycle. Therefore, though weld metal deposited by GMAW processes is significant (17%), its number of equipment installed is far less than the ratio of weld metal deposited by respective process indicates. It may be commented that Indian welding industry is dominated by SMAW equipments. For same productivity one GMAW source can replace four to five SMAW equipments. In this manner, the demand created for more number of SMAW equipments in the process makes some business sense to equipment manufacturers. Market demand pushes for manufacture of SMAW source. The number of SMAW equipments (N) engaged in Indian organized sector is

$$N = \frac{W_M}{d_{SMAW} D_{Av}} \quad (1)$$

Where W_M is total weld metal deposited per hour (Table II), d_{SMAW} and D_{Av} are average duty cycle and average deposition rate of SMAW equipment respectively. If one guesses (d_{SMAW}: 0.1 and D_{Av}: 0.5), for year 2010 – 2011, nearly 3.5lac equipments are in service for SMAW welding. Number of GMAW equipments would be much less, may be in the range of 35k. It is quite natural that equipment manufacturers of India concentrate more on SMAW equipments. Unfortunately, Indian arc welding equipments belong to old generations (Fig. 5), dominated by welding rectifiers and transformers. They have access only to weld gap, not electrical grid.

India has business market for arc welding equipments worth nearly $250 million – around 40% of it is manufactured in unorganized sector. Possibly, the turn-over of largest Indian manufacturers of arc welding inverters is only around $4 million. Unorganized sector consists of many small-time manufacturers – as small as one can possibly imagine. The business is so much fragmented that this industry is yet to hold even one meaningful seminar to know the status of arc welding equipments, to know each other in the industry etc. Even using SMAW process, a large multi-dimensional saving is possible (Table III) by adopting modern equipments. Everyone in the process should have compassionate feeling about the harm the prevailing process creates. Presence of large number of small to medium size organized players and rampant existence of small time players is one major obstacle for real growth. Design secrecy could also be one issue. Secondly, the way small time players are running the business, it may look apparent that the field is simple to roam around. It does not need expert inputs. Virtually no Indian institute covers arc welding equipment as part of curriculum (from power electronics point of view). Author is yet to find a meaningful article in prominent journals or proceedings of flagship conferences from India on modern equipments.

BASIC DESIGN INPUT FOR ARC WELDING EQUIPMENT

It is clear from Table III, that the role of arc welding equipment, apart from feeding energy to weld gap, is multidimensional and is beyond just weld gap and even welding process. Due to its capability to generate control features, welding equipment is most vital element in arc welding process. If the equipment helps attain three levels of compatibility, as shown in Fig. 4, majority of the associated problems are inherently taken care of. Combination of arc welding inverter and P-GMAW process achieves superior compatibility [7]. Level of compatibility is quantified (2) through goodness factor GF. It is explained below. Higher the GF better is the level of compatibility.

Optimization of SMAW dominated process would depend on

Table III : Comparison of role of equipment of two generations

	SMAW + Rectifier in India	SMAW+Inverter in W. Europe
Weld Gap Power	7.5 kW	7.5 kW
Weight of the equipment	>120 kg	<20 kg
Overall Electrical Efficiency	0.37	0.8 [18]
Energy meter reading	15 kW (Cable loss : 18%)	8 kW (Cable loss : 1%)
Grid Power drawn	23 kW	9.375k Unit
Energy consumption/year (Loading : 1000 hrs/year)	23k Unit	9.375k Unit
Yearly energy saving ($)	0	2000
Energy conversion efficiency	0.28	0.49
Equivalent fuel (coal) energy	82 kW	19 kW
CO_2 released per year	19 ton	4.3 ton
NO_2 released per year	19.3 kg	4.6 kg
SO_2 released per year	97 kg	15.6 kg

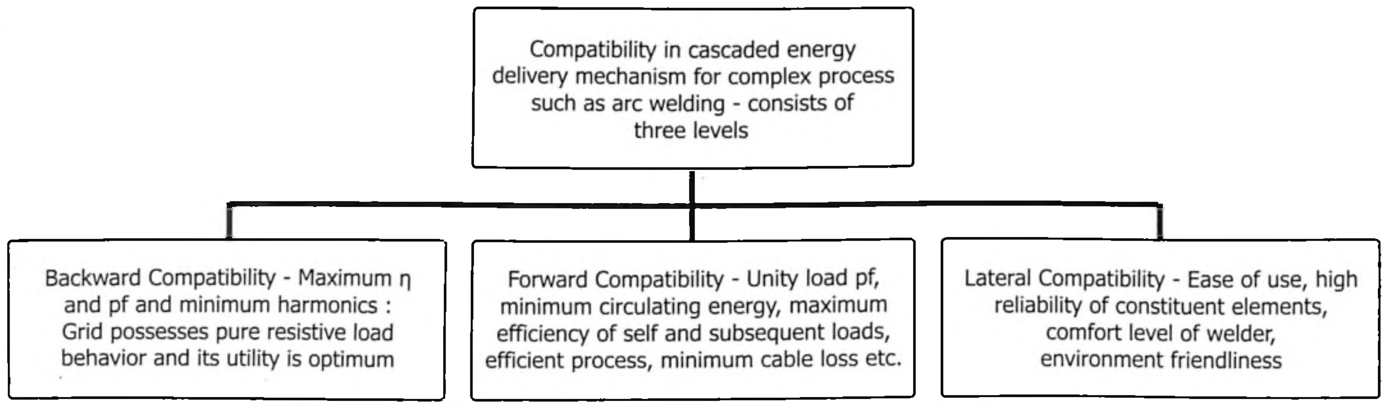

Fig. 4 : Constituent elements of compatibility in complex arc welding process

i) Settling time (τ_s) of equipment. Its smaller value is desirable.

ii) Compact and light weight equipment (W) for easy handling

iii) Unity pf and large η for reducing loss in facility, equipment etc

iv) Equipment should have excellent across the load efficiency η_{AL} as I_a vary over wide range.

To grade equipment qualitatively, let us define a term called goodness factor GF [7] for welding power source as

$$GF = \frac{\eta pf}{W\tau_s} \quad (2)$$

Numerator of Eq. (2) signifies how resources or grid power is handled where as its denominator takes care of process optimization. Expression of desired flat curve of η within complete output range of equipment is

$$\eta = \eta_{Max} \tanh(xI_a) \quad (3)$$

where maximum η i.e. η_{Max} should be high and 'x' is to incorporate flatness in it. E.g. to have flatness from minimum current of 30A for 6010 electrodes or low voltage low current 6013 electrodes onwards, Eq. (3) takes the form

$$\eta = \eta_{Max} \tanh(0.033I_a) \quad (4)$$

Expression of weight W and settling time τ_s could be written as

$$\tau_s = \frac{K_1}{f_s} \quad (5)$$

$$W = \frac{K_2}{f_s^q}; 0 < q < 1 \quad (6)$$

Value of K_1 depend on inverter topology, controller structure etc and Eq. (6) is partly valid if there is no fall in η at large f_s. Heat sink and cooling requirement is less at high η and magnetic and filter components are smaller at higher f_s. Using Eq. (4), Eq. (5) and Eq. (6) in Eq. (2), one gets modified expression of GF as

$$GF = \frac{\eta_{Max} f_s^{(1+q)} pf}{K_1 K_2} \cong K f_s^{(1+q)} \quad (7)$$

K is constant. Constituent parameters of GF vary favorably with one basic parameter Eq. (7) of inverter i.e. f_s. Higher the f_s, more GF is achieved. Cost, design complexity, reliability and η-vs-f_s trade-off are certain limiting factors. However, desirable journey of arc welding equipment is shown in Fig. 5. India still uses welding transformers and welding rectifiers operating at 50 – 300Hz range. India lags behind developed world by forty-odd years.

Impact factor (IF) demonstrates how much impact Eq. (8) new equipments would make, if a 400A rectifier is replaced

$$IF = \frac{GF_{Inverter}}{GF_{Rectifier}} = \frac{0.3496}{0.00012} = 2913 \quad (8)$$

New equipments (Table III) would draw benefits Eq. (8) in energy, productivity and quality, and makes process simpler.

RESEARCH AND DEVELOPMENT IN ARC WELDING EQUIPMENT: INDIAN PERSPECTIVE

One of the major outcomes of continuous evolution of arc welding process is birth of new methods to suit requirements that has many aspects and origins. One single prominent reason for persistent phases of evolution is availability of better welding equipment as shown in Fig. 5. It also shows the comparative position of Indian welding vis-à-vis that of developed countries. India still uses low frequency equipment. It will be difficult with such equipments to create viable technology base in welding. Continuous sustained research is required for development of efficient technology. In first eighty years when India was not even a passive player, the world saw only four major types of arc welding equipments [8] as: (a) welding transformer, (b) welding transformer plus rectifier, (c) electrical motor plus generator, and (d) engine driven generator. Subsequent twenty odd years the world saw introduction and fast maturing of SCR based controlled

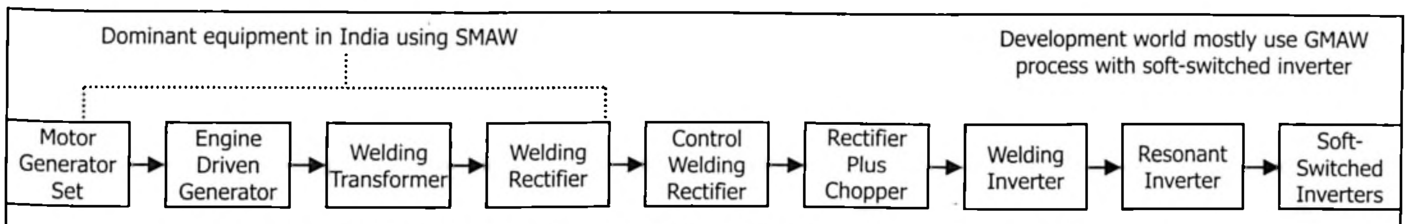

Fig. 5 : Evolution is towards higher switching frequency at primary

Table IV shows elements of goodness factor of prevailing equipment (rectifier) and that of soft-switched inverter.

Table IV : Goodness Factor for welding rectifier and welding inverter

	η	P*f*	W (kg)	τs (ms)	GF
400A Welding Rectifier (Indian process)	0.6	0.6	150	20	0.00012
400A Welding Inverter (Developed Countries)	0.92	0.95	25	0.1	0.3496

Table V : The journey in modern arc welding equipment

Product or process for practical use	App. year	Country	
Arc welding process	1881 [22]	Russia	N.N.Benardos invented (patent no. 12984) the process and successfully welded wrought iron, steel, bronze etc. He solved many problems the technology and technique of welding, selection of current source and devised suitable welding circuit
Motor generator set			They were all matured power sources by 1950s, mostly dominated by passive components. Majority of power sources have poor efficiency and power factor.
Welding Transformer			
Engine driver generator			
Welding rectifier			
Controlled welding rectifier	1960s	USA	Launching of Silicon controlled rectifier (SCR) enabled R&D professionals to successfully develop this product, very robust.
Rectifier + Chopper	1970	USA, Germany	Low voltage Mosfet and bi-polar transistor were made available for high frequency switching and control.
Transistor Inverter	1980 [11]	USA, Germany	High voltage switching device allowed primary control. It made both weld gap and grid parameters available for control.
IGBT based inverter	1983 [12]	USA	Ideal switch for primary control. It combines positive features of MOSFET for driving and bi-polar transistor for efficient power switching.
Resonant inverter	1993	Italy [13]	Reduced switching loss allows higher frequency of operation. Efficiency is better and the equipment is compact and light weight.
PS PWM inverter with ZVS	1997 [14]		It reduces turn on loss
PS PWM ZVS ZCS inverter	1997 [15]		It operates at high switching frequency and high flat efficiency curve, suitable for P-GMAW
Multi-functional inverter	2006 [16]		As equipment becomes active component dominant, it is able to meet weld gap characteristics of all arc welding methods
Hard-switched inverter with SiC	2011 [17]		It simplifies the inverter technology, achieves flat efficiency curve, compact, efficient.

welding rectifier and rectifier plus chopper. More control features were added. The period to maturity was sharp, as if, the research community of developed world just waited for necessary components to emerge. Arrival of SCR and MDSFETS as power switching devices were instrumental to accentuate transition. Emergence of sophisticated integrated circuits (IC) helped add superior control features [9] in arc welding equipments. It minimizes wastages such as in energy. However, all these models do not make resource compatible to process following Eq. (2). It either needs primary control or additional bulky capacitor bank. Introduction of high-voltage high-current bi-polar transistor [11] led to development of welding inverter technology. However, revolutionary change in inverter technology [12] took place once insulated gate bi-polar transistor (IGBT) emerged as power switching device. Subsequently, there has been emergence of large number of controllers and topologies to maximize GF. A few are listed in Table V. The transition to modern IGBT base inverter was prompt. Many of these developments took place with industries and institutes joining hands together.

Sustained research to excel has helped developed world to inch towards optimal performance of arc welding process. For sustained research, India lacks one basic element of the evolving field i.e. continuity. The origin is also missing. India did not have any significant presence in arc welding equipment till 1970s [23]. Major companies in developed world (e.g. Lincon Electric, ESAB, Miller, Fronius, Kempi, Panasonic, to name a few) that manufacture equipments have been players in this field for quite a long time. Continuity helps understand and memorize certain basic elements of a process such as impact or contributions of various inputs on the process, e.g. shielding gas combinations, electrodes etc. Though mode of control along with some inputs to the process may change, characteristic parameters of weld gap as load would remain same. It becomes easy for sustained players to translate the transition, e.g., from welding rectifier to inverter comfortably. When design need is well documented (as data base), it becomes simple for design team to translate into inverter module. Legacy of knowledge or knowledge bank is great asset. India lacked on that account.

India, as such, started using arc welding process very late. India produced first electrode in 1943, almost after sixty years of existence of the process internationally. Unfortunately, in India, traditional players manufacturing welding rectifiers and transformers have not shifted to design and manufacture of modern welding equipment, causing a virtual disconnect of continuity. Modern welding inverter, in particular, could not be looked into as mere power electronics equipment. Understanding the complexity of load is essential. That's why Japan makes GMAW equipment for CO_2 shielded atmosphere, whereas USA uses Argon and/or Helium, and Europe uses combination of argon and CO_2. Single equipment would not do for all gas combinations. The required power source characteristics for similar welding joint would be different. Power electronics engineers need to be concerned about the impact of shielding gas [10] on arc stability etc. Exchange of views and co-ordination among experts are vital.

Continuity was present among Indian entrepreneurs from welding transformers till rectifiers, but not on next phases such as choppers or inverters. India produces all basic materials for welding rectifier and transformer. However, virtually no significant input material for welding inverter and some for chopper are manufactured in India as shown in Table VI. This is a serious constraint. The idea of being a manufacturer of a valid item for inverter is – its components should be understood through detailed data sheet containing all functionality, thermal and reliability characteristics and it should have either design or application note. Sourcing proper input materials was not easy for most Indian manufacturers. Presence of component manufacturers enhances technology base of a country.

IGBT based welding inverters could be less than thirty years of age. There has been enormous number [13-16, 21] of topologies to cater different aspects and needs of arc gap such as speed of response, efficiency, power factor, reliability and compactness (power density). Across the load efficiency (η_{AL}) is another design pre-requisite of welding equipment. Inverters of Indian origin mostly operate at 20kHz. They are based on hard-switched topology.

MINDSET IN RESEARCH FOR ARC WELDING EQUIPMENT

It is important for any country to be in the fore front of scientific and technological research. Man (human) power, money, materials, motivation (attitude) etc. are major ingredients for research. Fortunately in welding, a few problems for research are known. Money and manpower both are serious problems in India as comparatively shown in Table VII. Research functions are normally handled on three fronts – government sponsored, corporate sponsored and at institutes. Institutes could be government funded or funded through projects. Impact of output of research on country's economic, energy and environment fronts etc. enthuse government agencies to pump money in a research project. It needs documented approach which is lacking in India. Though, in that sense arc welding process is important for India. Benefits of research in arc welding equipment are not properly quantified.

Corporate can pursue research in house or in association with institutes(s). Corporate houses need to do something more to revamp ailing technological research base in arc welding, in particular, and all fields in general. Indian enterprises spend only 3% of their sales [19] towards research, while elsewhere it is nearly 15%. India lacks in funds, manpower and materials (Table VII) to conduct basic research in welding equipments. Though, major materials are now made available, their cost-competitiveness is another concern. This makes cost of incoming material of indigenous welding inverter higher. Industrial sector deals with technology. Inflow of funds from

Table VI : Sources of basic raw materials of arc welding equipment							
	USA	Germany	China	Japan	Korea	Italy	India
Insulated gate bi-polar transistor (IGBT)	Yes	Yes	Yes	Yes	Yes	Yes	No
Polypropylene (PP) film capacitor (DC link)	Yes	Yes	Yes	Yes		Yes	No
Bridge Rectifier	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Complex low thermal resistance heat sink	Yes	Yes	Yes	Yes	Yes	Yes	No
ICs, micro-controllers,FPGA	Yes	Yes	Yes	Yes	Yes	Yes	No
Fast diodes for secondary rectifications	Yes	Yes	Yes	Yes	Yes	Yes	No
Power ferrite of all suitable sizes and shapes	Yes	Yes	Yes	Yes	Yes	Yes	A few
Litz wire for high frequency transformer	Yes	Yes	Yes	Yes	Yes	Yes	No
SiC MOSFET	Yes	Yes		Yes			
High current Schottky diodes	Yes	Yes					
Complex heat sink with low thermal resistance	Yes	Yes	Yes	Yes	Yes	Yes	No

Table VII : Comparative R&D expenditure and human resources [19]					
	India	China	Japan	USA	Korea
Comparative money inflow	$ 1	$ 5	$ 340	$ 250	$ 60
Manpower (Scientists & Engineers)	1	5	250	100	50

industrial sector should be major source for research in technology. At present, it is too small for India. Following comparative chart (Table VII) shows money inflow into Indian R & D sector vis-à-vis that in developed world. As prospect of continued research is bleak, less and less people are moving to this field as career (Table VII). It is reflected prominently as well in product development in arc welding.

Quality of man power is another major issue in business of Indian arc welding equipments. Secondly, it is hardly seen in Indian environment an R&D personnel sticking to his/her parent company for long. R&D personnel becoming entrepreneur is also not uncommon. Secrecy of design information becomes a serious concern. Moreover, one can hardly find a doctorate degree holder whose sole responsibility in an arc welding equip-ment manufacturing company is development of welding inverter. Ph.D. as a degree means something special. It is interesting to note that except for medicine, this qualification (Ph.D.) is same across all disciplines, for any subjects and conferred by any university or institutes. During Ph.D. program, a student is taught and guided as how to handle new challenges in his/her field. It could be in science and technology or in literature or in sociology, political science etc. Doctoral student can think about a problem or process it in mind philosophically, that helps generate more passion. He/she is equipped with mathematical aspects of physical process, can model it and gets requisite simulations done beforehand. Product development, then, becomes simple, more meaningful, and full of fun. The industry should be able to absorb more Ph.Ds. This is one hope each organization should try in India.

CONCLUSION

India pays heavy price for walking with the fallacy that energy cost in arc welding process is negligible. Actually, major quality engineering problems in arc welding have origin on how energy or heat input to weld gap is being controlled. Multiple modes of activities in extremely wide and different time scales exist in the process. Arc welding equipment plays a catalytic role to dynamically control energy. Therefore, its proper design is very important for any applications. Let the design be application centric.

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