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AMORPHOUS METAL CORE CHALLENGES AND OPPORTUNITY FOR ENERGY EFFICIENT 600 HZ POWER SYSTEMS

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This paper presents energy efficient three phase 600Hz power system using amorphous metal core for industrial and commercial zones which require high efficiency, less weight and space for the equipments. An experiment has been conducted on 40 Watt, 220V fluorescent tube light with 600Hz and 50Hz supply. The results show that the 600Hz system is efficient than 50Hz power system. A three phase parallel resonant inverter circuit has been modeled and simulated using MATLAB/SIMULINK. XLPE Power cables are used for transmission which reduces the inductance drop. Further for compensating line voltage drop and unbalance voltage, Thyristored Switched Capacitors are adopted. An application example of high frequency drive systems used in synthetic yarn textile industrial drives is explained.

Key words: amorphous metal core, hysteresis component of magnetic losses, energy efficiency, parallel resonant inverter,

1. INTRODUCTION

On April 13, 1982, the Duke Power Co energized an experimental pad - mount distribution transformer in Hickory, North Carolina [14]. The transformer was manufactured by General Electric, to provide electric power to local residence. In the same month, the Georgia Power Company installed a similar transformer made by Westinghouse Electric in Athens, Georgia. It supplied electricity for the exterior lights at the Westinghouse Newton Bridge Road Plant. Both the transformers were manufactured with Fe-B-Si amorphous – metal alloy. By replacing grain-oriented silicon steel in the transformer cores, the amorphous metal core reduced the core losses of the transformer by 75%. Demand for electrical energy is increasing at a very rapid pace and unable to cope with this increasing demand. This paper describes an energy efficient *600Hz* power system. Aircraft and space vehicle industries use *400 Hz* frequency for hydraulic pumps, fuel boost pumps, fuel jettison pumps, override fuel pumps, flaps and slats electric motors because of lesser weight and smaller size of the electric equipments [3] [4] [9]. The needs for high frequency power supply for industries, commercial and domestic utilities are also increasing [2] [4]. With the development of modern power semiconductor devices like GTO, BJT, IGBT.IGCT and MOSFET [1] many different frequency power supplies have been increasingly employed in most of the industries, offices and domestic applications. MOSFET and IGBT have replaced bipolar junction transistor almost completely. The *600Hz* centralized power system found major attention as an alternate to the conventional *50/60 Hz* supply for industrial and commercial zones. Using amorphous core, the reasonable operating frequency would range from *400Hz* to *1 kHz.* The *600Hz*-power system is suitable for a *20 km* by 20 *km* industrial zone or *1km* by *1km* commercial areas.

2. THE DISCOVERY OF AMORPHOUS METALS

Metal alloy typically possesses crystalline atomic structures in which individual atoms are arranged in ordered, repeating patterns. Amorphous metal alloys differ from their crystalline counterparts in that they consist of atoms arranged in near random configurations devoid of long rang order. Although such noncrystalline structures are common in nature, they have normally been associated only with nonmetallic systems.

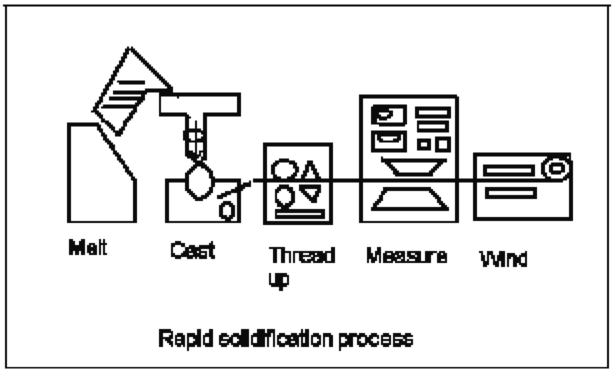

Figure 1. Manufacturing of Amorphous Metal Core

Fig 1 shows the rapid solidification processes of manufacturing of the amorphous metal. The disordered liquid structure is preserved when the cooling rate is sufficiently great to prevent atoms or molecules from aligning into ordered, crystalline configurations. In silicates, which consist of three-dimensional atomic clusters, the liquid state is viscous. Individual molecules have limited mobility and crystallization proceeds slowly. By contrast, liquid metal alloys are characterized by low viscosity and high diffusivity, partly because they consist of loosely bonded atoms rather than bulky molecules. The individual atoms in a liquid metal alloy can move about and freely. On cooling, atomic rearrangement and crystallization occur rapidly, suggesting that extraordinary cooling rates would be necessary to bypass crystallization. The discovery of amorphous metal is generally credited to P.Duwez, who in 1960 produced amorphous samples by rapidly quenching an $AU_{75}Si_{25}$ alloy from the liquid state. Duwez used a pressurized gas gun to propel small droplets of molten alloy onto a polished copper plate. On the impact, each droplet deformed into a thin film. Intimate contact with the highly conductive copper plate allowed the molten film to cool rapidly and solidly into flake or splat form. Fig.2.

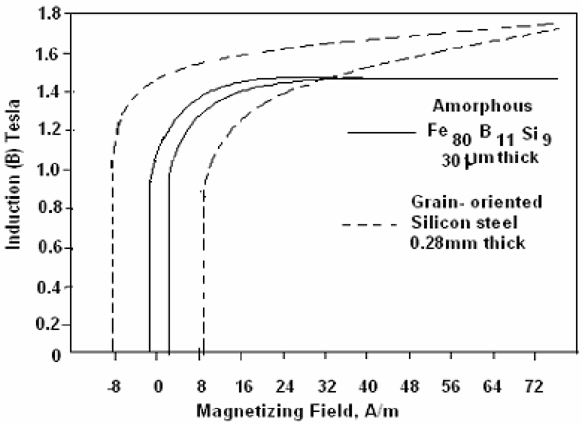

Figure 2. B-H loop of amorphous $Fe_{80}B_{11}Si_9$ and grain oriented silicon steel

Shows the *B-H* loop of amorphous $Fe_{80}B_{11}Si_9$ and grain – oriented silicon steel [7]. The narrowness of the *B-H* loop for an amorphous metal is the high permeability *(B/H),* and the low hysteresis loss [10]. The components of magnetic losses are measured by the area within the *B-H* loop, which indicates the relative ease of magnetization. The atomic disorder and high solute content of amorphous metals limit the mean –

free path of electrons, which results in electrical resistivity of two to three times of the grain oriented silicon steels. The thin gauge of amorphous metals, typically 30 *μm* compared to 0.28 *mm* for grain oriented silicon further increase the total electrical resistance. Infrared analysis indicates that the grain- oriented silicon –steel unit reaches an average temperature of $332\ K\ (59^0\ C)$. Comparable operation of the most efficient amorphous – metal core results in a smaller temperature rise of about 304 $K\ (31^0\ C)$ [7]. The amorphous metal cores are used in *600 Hz* power systems.

Table 1 Physical properties of Amorphous metal core

S.No	METGLAS 2605SA1	Parameter
1	Ribbon Thickness (µm)	25
2	Density (g/cm$^{3)}$	7.18
3	Saturation Flux density (Tesla)	1.56
4	Electrical Resistivity (µ- Ω-cm)	137
5	Continuous Service Temperature	150
6	Thermal Expansion (ppm/ºC)	7.6
7	Crystallization temperature (ºC)	510
8	Curie Temperature ((ºC)	395
9	Tensile strength (MN/ m$^{2)}$	1k– 1.7k
10	Elastic Modulus (GN / m^2)	100 - 110

3. PHYSICAL PROPERTIES OF AMORPHOUS METAL CORE

Amorphous Metal Core physical properties are mentioned in the table.2 The operating flux density is 1.56 T. Low profile – enables weight and volume reduction upto to 50%. Low temperature rise enabling smaller compact designs. Amorphous Metal Copre has Low loss – resulting from micro – thin METGLAS ribbon (25 µm)

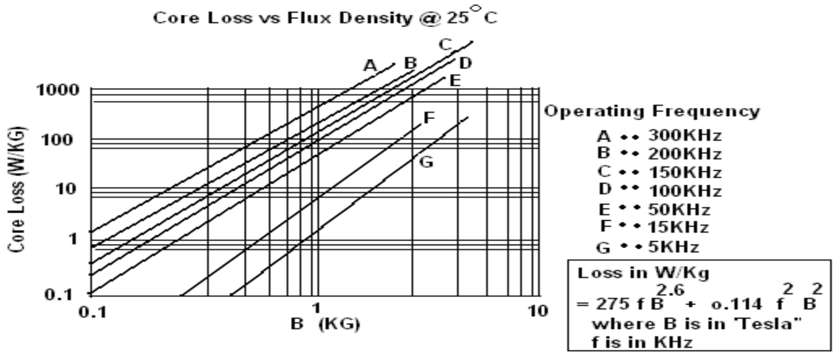

Figure 3. Amorphous Metal core - loss Vs Flux Density

Fig.3 shows the core loss Vs flux density of the amorphous metal core. The maximum operating frequency of the core is 300 kHz. The narrowness of the *B-H* loop for an amorphous metal gives the high permeability *(B/H),* and the low hysteresis loss. Hence the core finds applications in UPS and SMPS power factor correction chokes, UPS harmonics filter inductors, high power outdoor industrial ballasts, welding power supplies, high-speed rail power systems. The core finds application in hot- spot temperature working conditions up to class F.

4. EXPERIMENT ON A FLUORESCENT LAMP USING AMORPHOUS CORE

Fig. 4 shows a single-phase parallel resonant inverter, designed to produce *220V, 600Hz* to glow a *40-watt* fluorescent tube light. The inductor *L1* acts as a current source and the capacitor *C1* is the resonating element. *Lm* is the mutual inductance of the transformer *T1* and acts as the resonating inductor. A constant current is switched alternatively into the resonant circuit by MOSFETs *Q1* and *Q2*. The output *220V* of the transformer *T1* is given to the *40Watt* tube light and *10V* transformer tap is connected to oscilloscope to measure the resonant waveform. The tube light choke *L2* is designed with Amorphous Metal Core –Metglas 2605SA1. The control unit generate square wave to trigger the MOSFETs. Fig 5 shows the parallel resonant circuit. An experiment has been conducted on *40 Watt, 220V* fluorescent tube light with *600Hz* and *50Hz* supply.

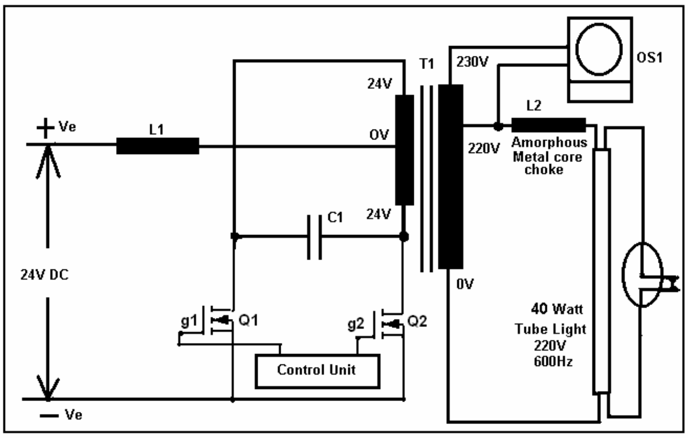

Figure 4. Experiment setup of single phase parallel resonant inverter with 40W tube light

The inductance required for the conventional choke at *50Hz* is *820mH* but at *600Hz*, the inductance requirement is only *72mH*. At *600Hz*, the tube striking voltage is *125V*, which is much lesser than *165V* at *50Hz*. Fig 4 shows the parallel resonant circuit [5] [6]. It is supplied from a current source so that the circuit offers high impedance to the switching current. The damped – resonant frequency ω_r *600Hz* is given by [14]: $\omega_r = \left[\frac{1}{LC} - \frac{1}{4R^2C^2}\right]^{1/2}$

Table 2

Comparison of 50Hz and 600Hz Choke in 220V, 40Watt fluorescent lamp.

Core used	Silicon steel	METGLAS Amorphous alloy 2605SA 1	Experiments Results
Supply Frequency at *220V*	*50Hz*	*600Hz*	---
Thickness of core *(mm)*	0.35	0.022	Core thickness is reduced by 94%
Rated Current *(A)*	0.40	0.40	----
Number of Turns *(T)*	2094	455	Number of turns is reduced by 78.3%
Inductance *(mH)*	820	72	Inductance of the choke is reduced by 91.21%.
Copper Loss *(W)*	6.2	1.47	Copper loss is reduced by 76%,
Iron loss *(W)*	12	3.4	Iron loss is reduced by 72%
Weight of the core *(g)*	408	72	Weight of the core is reduced by 83%
Weight of the copper *(g)*	122	32	Weight of the copper is reduced by 74%
Volume *(cm^3)*	169.2	47.1	Volume of the choke is reduced by 72%

Table 2 shows the comparison parameters of the chokes used for *50Hz* and *600Hz* supply. From the table 2 it has been seen that 600Hz amorphous metal choke reduces *76 %* of copper loss and 72% of iron loss, in addition to that weight and size of the choke is also reduced to *83 %* and *72 %* of the *50Hz-*silicon choke.

5. MATLAB / SIMULINK SIMULATION

Matlab / simulation has become a very powerful tool in industry application as well as in academics, nowadays. A three phase *415V, 600Hz*, parallel resonant inverter is simulated using MATLAB / SIMULINK to supply a load of 5kW. Fig. 5 shows the single line diagram of three phase simulation circuit. The circuit consists of three phase converter, three numbers of identical single phase parallel inverter circuits with 120^o phase shift, transmission line resistance, inductance and capacitance, *TSC* and *5kW, RL* load. To maintain voltage regulation, thyristored switched capacitor-*TSC* is added to the circuit. Fig.6 shows the waveform of simulated three phase resonant inverter. In the simulation circuit, cable inductance, resistance and capacitance are added.

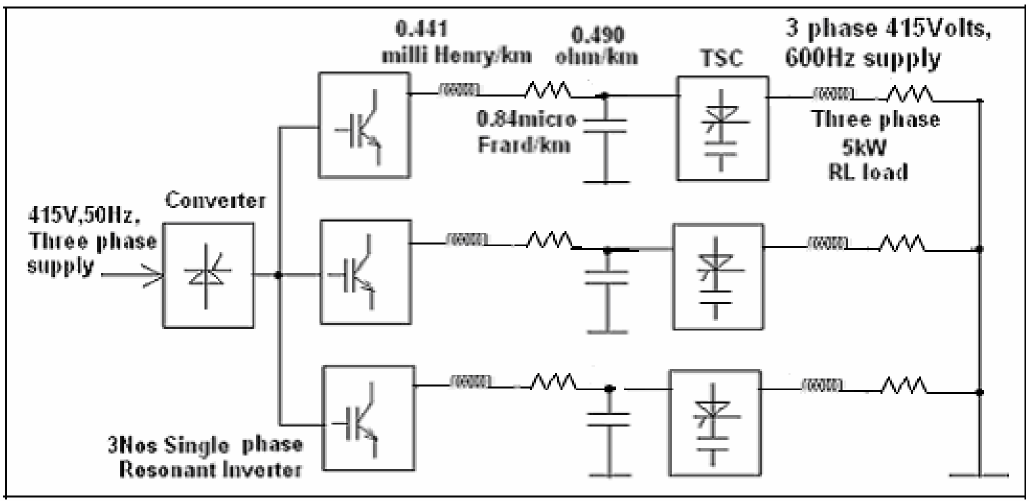

Figure 5. Single line diagram of three phase resonant inverter circuit with TSC

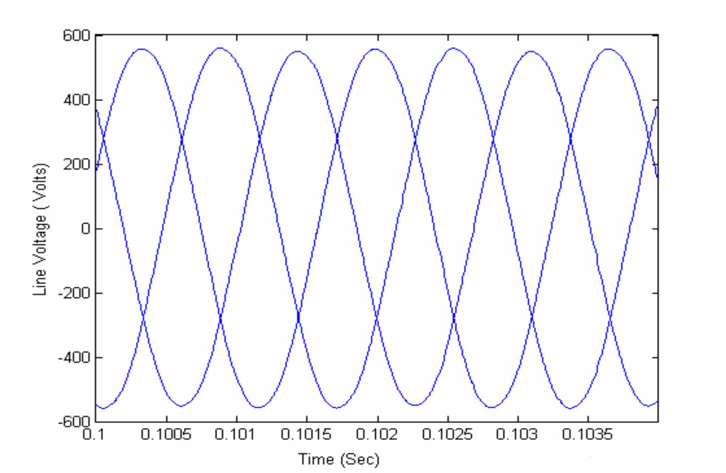

Figure 6. Three phase output- 600Hz wave form from Matlab Simulink simulation

6. PROPOSED HIGH FREQUENCY POWER SYSTEM CONFIGURATIONS

Fig. 7 shows the proposal of 600*Hz*-power system. The system consists of three phase full wave rectifier, chopper, three phase resonant inverter, XLPE power cable, solid state circuit breaker and thyristor switched capacitor - *TSC*. Microcontroller PIC16F877 is used to control the *DC* Link voltage. Trigger pulses for inverter and *TSC 1 & 2* are produced by the microcontroller. *TSC2* will suppress the very fast fluctuating line voltage. Since line voltage distribution along the transmission line is affected by the loading conditions, it is necessary to compensate the voltage drop of the cable at inductive loads. This is achieved by injecting leading reactive power to the line by the *TSC2* [8]. The three phase resonant inverter produce the three phase A.C. output. The Naturally commutated cycloconverter will replace the PWM inverters in many applications, offering high efficiency and reliability. The solid-state circuit breaker, resonant inverter, amorphous metal core transformer can be used effectively in commercial power system. Capacitors can be made much smaller as about 1/12 times with low cost. Distributed natural energy generation and co-generation systems can be directly used for the energy source of the *600Hz*-power system. Higher frequency power supply will be used in steel plants, chemical plants for compressors and induction heating. The system will be effectively used in commercial areas and intelligent buildings. Large reduction in size of the transformer and reactor by 1/3 to 1/4 times is possible.

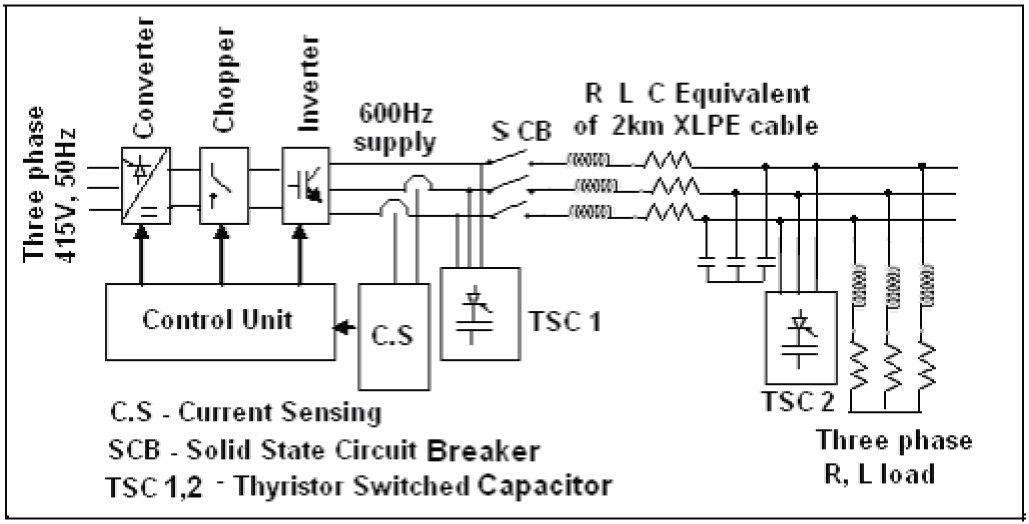

Figure 7. Proposed 600*Hz* Power System

7. CONCLUSIONS

This paper presents a *600Hz* power system for supplying particular areas such as industrial zones, commercial complex, intelligent buildings and offices, where high efficiency, less weight and space for the equipments are desired. An experiment has been conducted on *40W* fluorescent lamp with *220V, 600Hz* with amorphous choke and *220V, 50Hz* with silicon steel choke. In the experiment, using 600Hz power supply system, the efficiency is increased and losses, space, weight of the choke are reduced. The weight of the core is reduced by *83%,* iron loss is reduced by *72%*, copper loss is reduced by *76%*, weight of the copper is reduced by *74%,* volume of the choke is reduced by *72%* and inductance of the choke is reduced by *91.21%.* The *600Hz* power system will be useful for HDL lamps, high-speed induction motors, induction heating, DC power supply, cycloconverter fed motors drives in steel, chemical plants and synthetic yarn textile industry. The 600*Hz* power system is suitable for a 20*km* by 20*km* industrial zone or 1*km* by 1*km* commercial areas is proposed.

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