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Estimating Reliability of Power Factor Correction Circuits: A Comparative Study

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Abstract
Reliability plays an important role in power supplies, as every power supply is the very heart of every electronics equipment. For other electronic equipment, a certain failure mode, at least for a part of the total system, can often be tolerated without serious (critical) after effects. However, for the power supply no such condition can be accepted, since very high demands on the reliability must be achieved. At higher power levels, the CCM boost converter is preferred topology for implementation a front end with PFC. As a result significant efforts have been made to improve the performance of high boost converter. This paper is one the effort for improving the performance of the converter from the reliability point of view. In this paper a boost power factor correction converter is simulated with single switch and interleaving technique in CCM, DCM and CRM modes under different output power ratings and the reliability. Results of the converter are explored from reliability point of view.
Keywords—Reliability , Powerfactor Correction, Boost Converter, Simulation of converters

I. INTRODUCTION

Reliability is the probability of operating a product for a given period of time without failure under specified conditions and within specified performance limits. It plays an important role in power electronic systems by which the number of system failures, repair costs, guarantee and etc are estimated. Every day the dependency upon the continuous availability of electronic equipment grows. Examples include telephone systems, computers supporting stock markets, and industrial control equipment for everything from semiconductors to petrochemicals. This means the power supplies supporting this equipment must perform without interruption even when one or more faults occur. The design emphasis in power-electronic systems is primarily on (apart from production cost) efficiency, power density and quality; the assumption being, if these criteria are met then, once a power-electronics product or system is in service, it will last for a long time (that is, have a high mean time to failure or MTTF). This is not a rational expectation and as such, many of the power-supply and power-system industries are faced with the daunting reality of random product and system failures in the field at a steady rate, which, ironically, is costing the industries a whole lot. There are some additional problems. First, an expensive customer-support engineering group is required just to handle these cases of failures. Second, the customers often refuse to accept a remedied or replaced product/system unless they are told the cause of the failure in the first place.

Third, reverse engineering of a failed product/system is a difficult (if not impossible) and time-consuming problem and require dedicated engineers. Therefore, recently, many power-supply/power-system industries have expressed the need for investigating failure modes of their products/systems to significantly increase the MTTF and the mean time between failures (MTBFs). However, this is easier said that done and requires an extensive multidisciplinary effort[1].

Reliability Definition:

Reliability is a discipline that combines engineering design, manufacture, and test. An efficient reliability program emphasizes early investment in reliability engineering tasks to avoid subsequent cost and schedule delays. The reliability tasks focus on prevention, detection, and correction of design deficiencies, weak pans, and workmanship defects with the goal of influencing the product development process and producing products which operate successfully over the required life. The reliability of a product can only be established if reliability is designed in, proper quality–controlled inspection and manufacturing assured; and maintenance procedures carried out. Improvement in reliability occurs when reliability information, obtained from test and field data, is analyzed and then, through an iterative feedback[1-2].

Reliability Function:

The reliability of a component can be described as an exponential function. The probability of finding a component operating after a time period is defined as:

$$R(t) = e^{-\lambda t} \quad \textbf{(1)}$$

Where λ is the constant failure rate during the useful life period.

The mathematic mean value of R (t) occurs at t equal to 1/ λ. 1/ λ is the mean time elapsed until a failure occurs, or the ‘‘Mean Time To Failure”, MTTF.

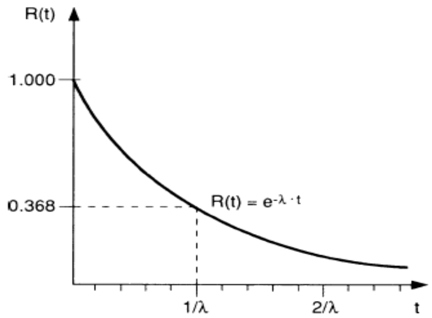

FIG.1 RELIABILITY CURVE

MTBF (Mean Time between Failures): As repair time (MTTR) normally can be neglected compared to MTTF for electronics, MTBF can be found as:

MTBF = MTTF + MTTR
≈ MTTF =1/ λ

MTBF or the failure rate can be calculated using different kinds of input data.

Calculation of MTBF For Equipment:

When calculating the MTBF for equipment, its total failure rate λ_e must be found. Normally the assumption is that all components are needed for operation. Consider an equipment or apparatus containing n components.

The probability to find n components in operation after the time t is:

$$R = R1 \cdot R2 \cdots\cdots\cdots R_n = e^{-\lambda 1 \cdot t} \cdot e^{-\lambda 2 \cdot t} \cdots\cdots\cdots e^{-\lambda n \cdot t} = e^{-(\lambda 1 + \lambda 2 + \cdots\cdots \lambda n) \cdot t} = e^{-\lambda t} \quad (2)$$

And

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \cdots\cdots\cdots + \lambda_n \quad (3)$$

The total failure rate for the equipment at specified conditions is accordingly achieved as:

$$\lambda_e = \lambda_{b1} \cdot c_1 + \lambda_{b2} \cdot c_2 + \cdots\cdots\cdots + \lambda_{bn} \cdot c_n \quad (4)$$

By simply inverting this value, the MTBF figure for the equipment is found:

$$MTBF = \frac{1}{\lambda_e} \quad (5)$$

Estimation Of Necessary Repair/Service Actions: Statistics can be used to get an idea of the service actions necessary for an equipment during its lifetime. The probability that the equipment will function without failures during a certain time is:

$$R(t) = e^{-\frac{t}{MTBF}} \quad (6)$$

(7)

Where t = the time during which the product shall operate under stated conditions. From this probability the end user can estimate the number of service/repair actions that can be expected for a certain product during its lifetime.

Calculation of Spare Parts Requirements: The MTBF value can also be used to calculate the number of spare parts required for a given unit/component. The calculation is based on the faulty unit/component being replaced by a spare part and no repair is carried out on site.

$$Q = N \cdot \frac{T}{MTBF} \quad (7)$$

(8)

Where Q = number of spare parts, N = number of operating products and T = expected equipment life time

Design Rules: It is well known that the temperature has a great influence on reliability. Often ‘‘rules-of-thumb’’ are used for correlating one failure rate figure with another. One of these rules indicates that the figure doubles for every 7-10°C increase in temperature. That rule takes for granted that all products are built following the same principles, and that components are equally utilized (i.e. chip temperatures are equal at given ambient temperature, etc.)[2][5].

This is of course not true. One equipment/unit may use semiconductors at a temperature close to the ratings which the component supplier gives as maximum ratings, while another equipment/unit may have a built in security in terms of utilization of lower temperature. Some of the later experiences show that the failure rate will double for every 15-20˚C increase during normal temperature conditions. Since the temperature influence on the reliability can be described as an exponential function, it is obvious that these ‘‘rules-of-thumb” must be used carefully.

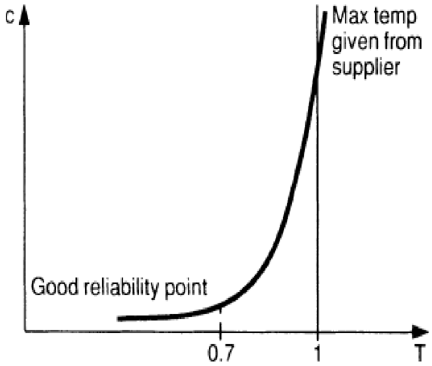

FIG. 2 APPROXIMATE CURVE FOR THE RELIABILITY AND TEMPERATURE

An approximate curve of the relation between failure rate and temperature has been shown in fig. 2.Another ''rule-of-thumb" which can be more valuable, signifies that at 0.7 T_{max} good reliability can be expected . Note that for semiconductors , +150 or +175 ˚C is often guaranteed as T_{max}. In consideration of these figures , the chip temperature of semiconductors should be kept below +105 and +125˚ C respectively. Far too often this figure is exceeded, especially for power handling equipment. Keeping chip temperature low, in conformance with this design rule, will remarkably increase the reliability of equipment.

In this paper the MOSFET is preferably chosen as IXFH12N100Q/IXS, the Diode MUR850 and the input bridge KBPC_35_06.

II. SINGLE SWITCH BOOST PFC RECTIFIER

A. Continuous Conduction Mode of Operation:)

The operation of Boost PFC converter for Continuous Conduction Mode can be studied under voltage control mode and current control mode. The current control mode is studied under three modes namely peak current mode control, average current control mode, hysteresis current control mode.

a) Peak Current Mode Control

The current control signal i* which is a scaled input voltage determines the peak of the inductor current i_L, the sinusoidal current reference. This reference is usually obtained by multiplying a scaled replica of the rectified line voltage vg times the output of the voltage error amplifier, which sets the current reference amplitude. The active switch in the boost converter is turned on at the beginning of each switching cycle. The switch is turned on at constant frequency by a clock signal. As soon as the inductor current i_L reaches i*, the switch is turned off. The process repeats. In this way, the reference signal is naturally synchronized and always proportional to the line voltage, which is the condition to obtain unity power factor.

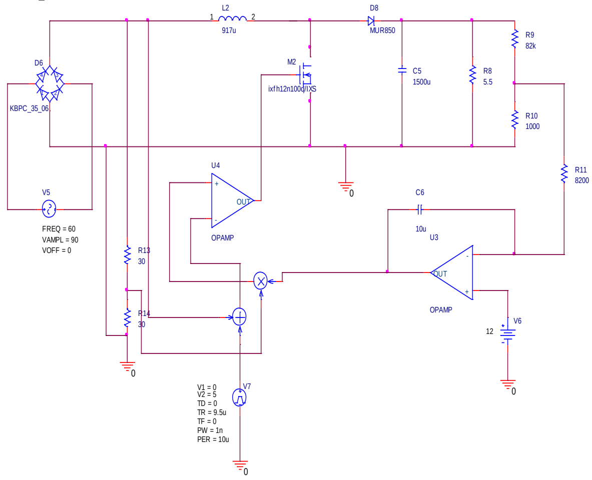

FIG. 3 TOPOLOGY FOR PEAK CURRENT MODE CONTROL

b) Average Current Mode Control:

The inductor current is sensed and filtered by a current error amplifier whose output drives a PWM modulator. In this way the inner current loop tends to minimize the error between the average input current ig and its reference. This latter is obtained in the same way as in the peak current control. Its advantage over the peak current mode control is that the stability ramp, which is mandatory for the peak current mode control, is eliminated.

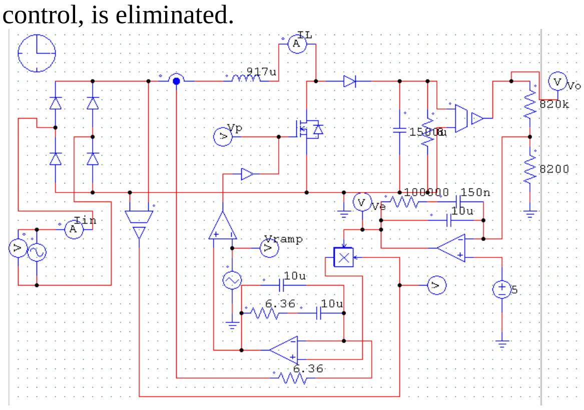

FIG. 4 SIMULATION DIAGRAM FOR AVERAGE CURRENT MODE CONTROL USING PSIM

c) Hysterisis Current Mode Control:

The upper inductor current reference is a half sinusoidal denoted $I_p$sinωt, with peak amplitude of Ip. The lower current reference is a half sinusoid, denoted $I_c$sinωt, with peak amplitude of I_C. The average inductor current, which has only the 120 Hz component of inductor current, is a half sinusoid, denoted $I_m$sinωt. The inductor current ripple is δsinωt, where δ is the peak current ripple. Since the inductor current switches at a much higher rate than the line voltage, the line voltage is assumed constant in each inductor current switching cycle

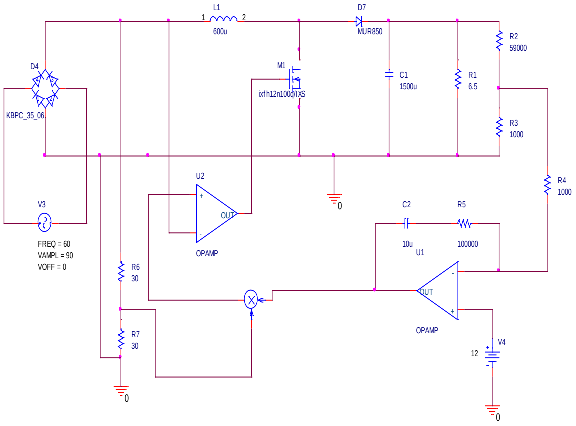

FIG. 5 TOPOLOGY FOR HYSTERISIS CURRENT MODE CONTROL

For any of the above current control mode techniques, the inductor wave form is as shown in Fig.

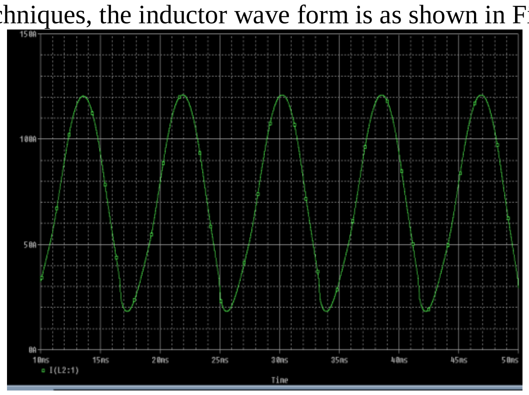

FIG. 6 INDUCTOR CURRENT WAVEFORM

B. *Discontinuous Mode of Operation:*

The operation of Boost PFC converter for Continuous Conduction Mode can be studied under voltage control mode and current control mode. The current control mode is studied under three modes namely peak current mode control, average current control mode, hysteresis current control mode.

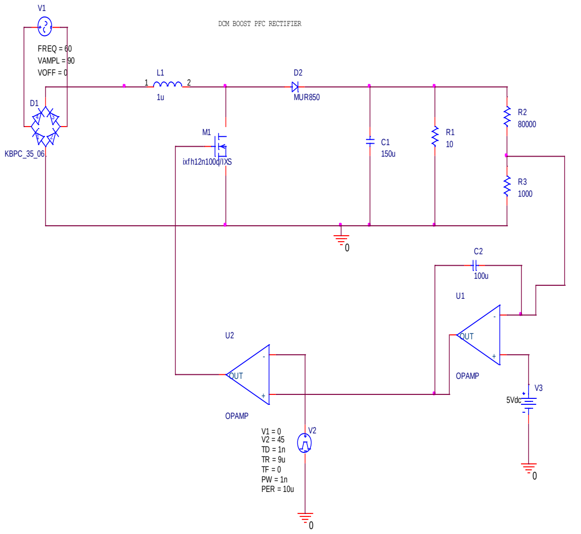

FIG. 7 SIMULATION DIAGRAM FOR DISCONTINUOUS MODE OF OPERATION

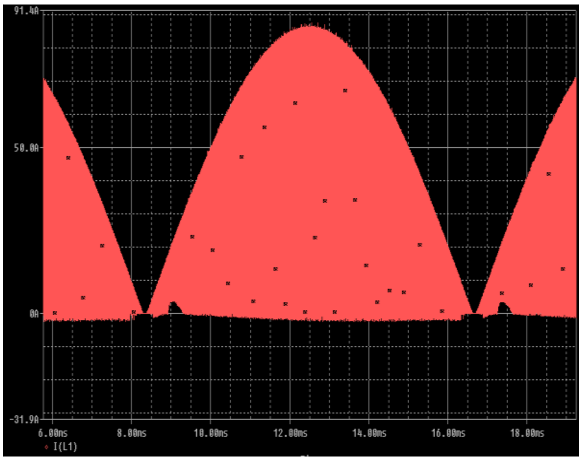

FIG. 8 INDUCTOR CURRENT WAVEFORM

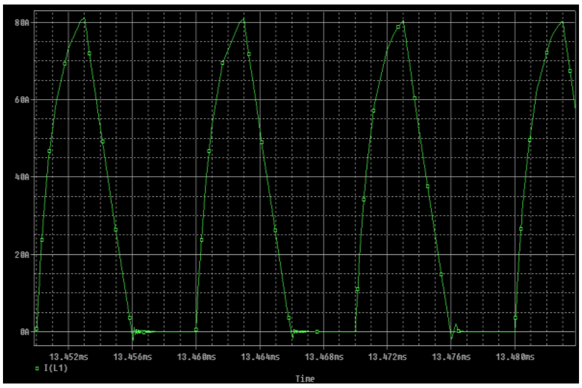

FIG.9 INDUCTOR CURRENT AFTER ZOOM

C. *Critical Boost PFC Rectifier*

The operation at the boundary of CCM and DCM was considered "constant on-time" for the boost switch. However, due to finite switching frequency and capacitor filter effect, the switch turn-on time varies throughout the entire cycle. This variation of the switch "on-time" affects the average switching frequency and the circuit component selection criterion. The control switch turns on when the inductor drops to zero and turns off when the inductor current reaches the peak inductor current envelope. The actual inductor current presents a saw tooth-type wave shape[4]

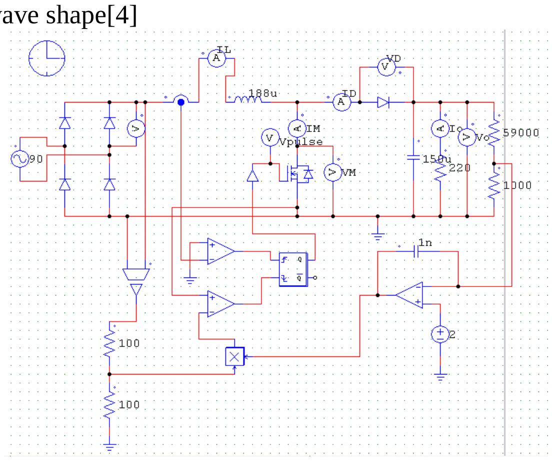

FIG. 10 SIMULATION DIAGRAM FOR CRITICAL CONDUCTION MODE

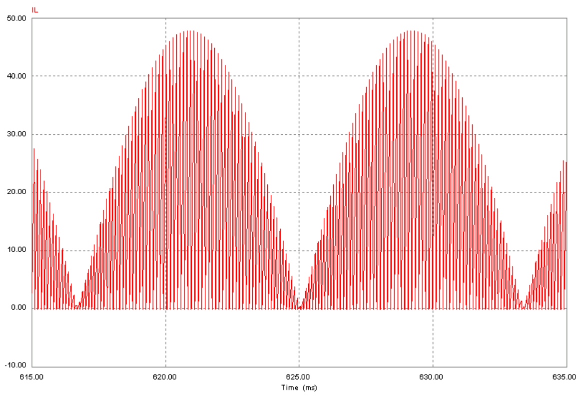

FIG.11 INDUCTOR CURRENT WAVEFORM

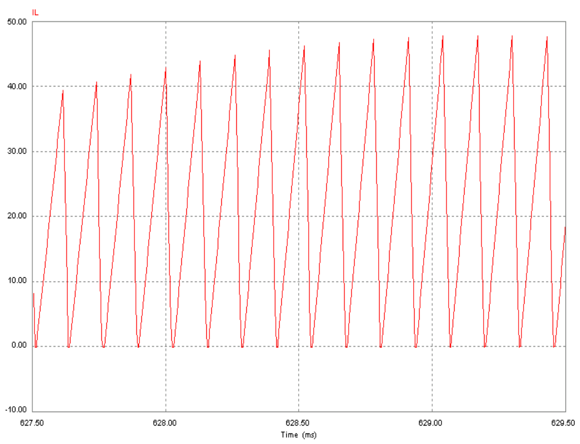

FIG.12 INDUCTOR CURRENT WAVEFORM AFTER ZOOM

III. INTERLEAVED BOOST PFC

Interleaved converters offer several advantages over single-power stage converters; a lower current ripple on the input and output capacitors, faster transient response to load changes and improved power handling capabilities at greater than 90% power efficiency

D. *Continuous Conduction Mode*

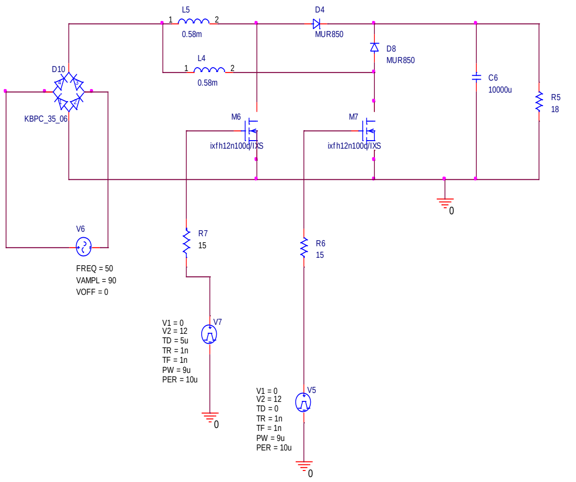

FIG. 13 SIMULATION DIAGRAM FOR INTERLEAVED BOOST PFC RECTIFIER FOR CCM MODE OF OPERATION

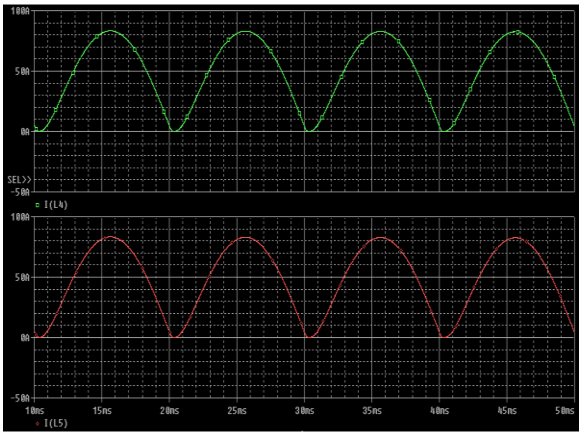

FIG. 14 INDUCTOR CURRENT WAVEFORMS FOR CCM MODE OF INTERLEAVING TOPOLOGY

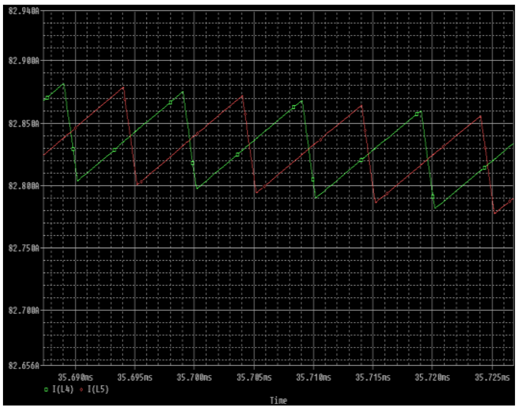

FIG. 15 INDUCTOR CURRENT WAVEFORMS AFTER ZOOM

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

E. Discontinuous Mode of operation

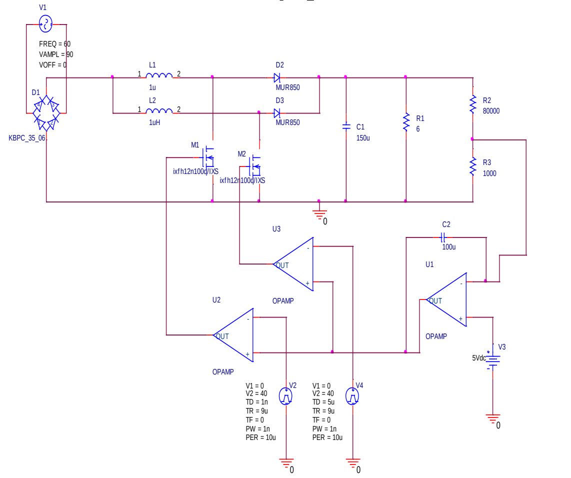

FIG. 16 SIMULATION DIAGRAM FOR DCM MODE INTERLEAVING TOPOLOGY

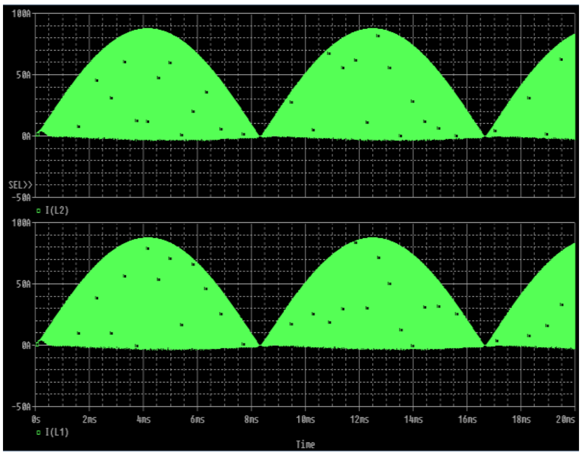

FIG. 17 INDUCTOR CURRENTS FOR INTERLEAVED BOOST TOPOLOGY

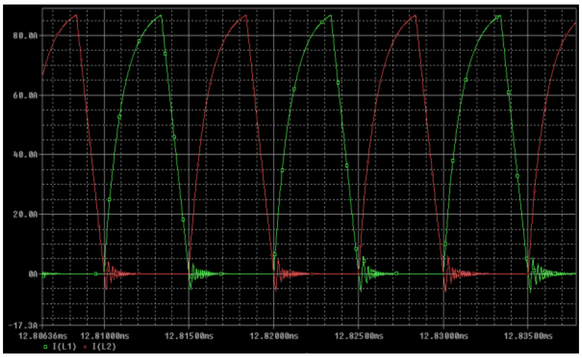

FIG. 18 INDUCTOR CURRENTS WAVEFORMS AFTER ZOOM FOR INTERLEAVED DCM BOOST

F. Critical Conduction Mode

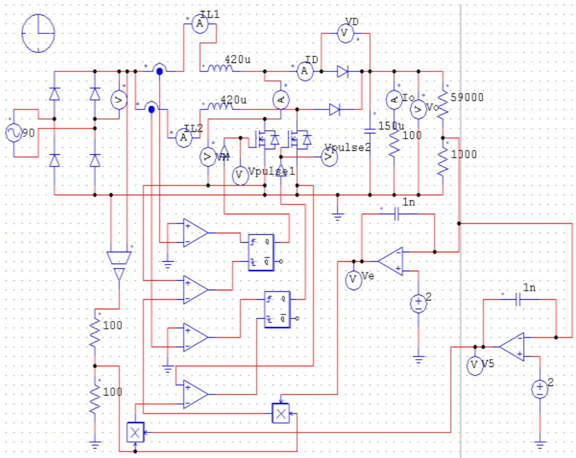

FIG. 19 INTERLEAVING BOOST PFC TOPOLOGY

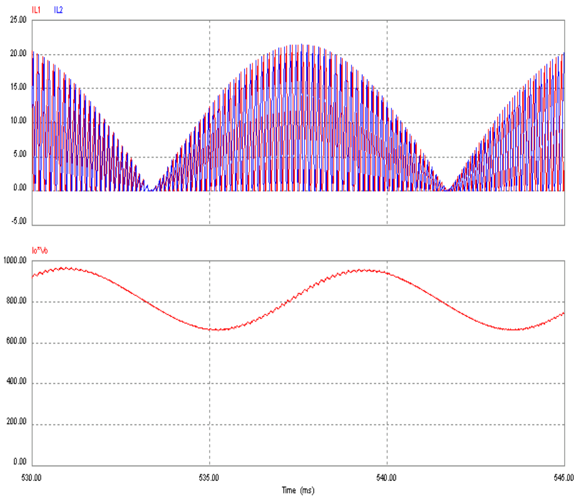

FIG. 20 INDUCTORS CURRENT WAVEFORMS

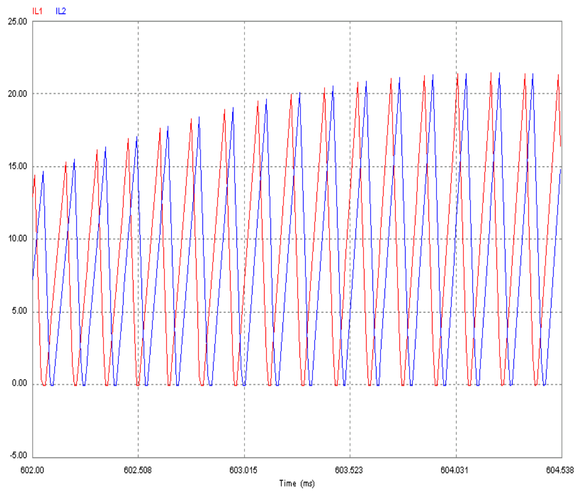

FIG. 21 INDUCTOR CURRENT WAVEFORMS AFTER ZOOM

IV. RELIABILITY CALCULATIONS

In this section, reliability of the boost converter in 1200 W output power and Peak Current Mode control is calculated and presented in details. For different output powers and operating modes, results of reliability calculations are shown in Table. 3. The part counting method is used to calculate reliability. In this approach, first the failure rate of each element in the converter structure is obtained individually and then the value of the converter's MTBF is calculated from equation (4) that "N" is the number of consisting parts. For these calculations the following assumptions are made;

1. The ambient temperature is $27^\circ C$
2. The control structures of these converters are not the same whose reliability can be neglected for comparing the reliability of main components.

To calculate the reliability, first the dynamic and static losses of MOSFET and Diodes should be calculated for different output powers working in three operating modes namely CCM, DCM and CRM.

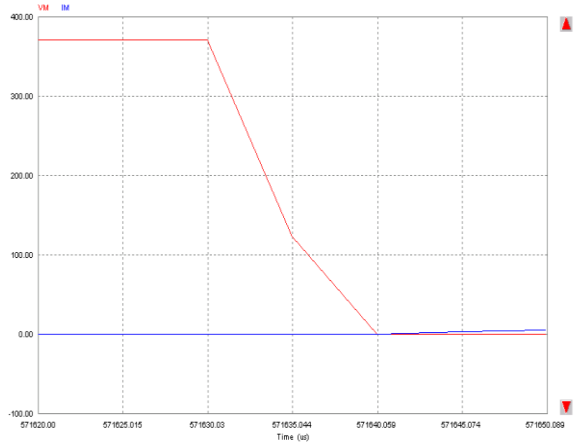

FIG. 22 TURN- ON OVERLAP WAVEFORM

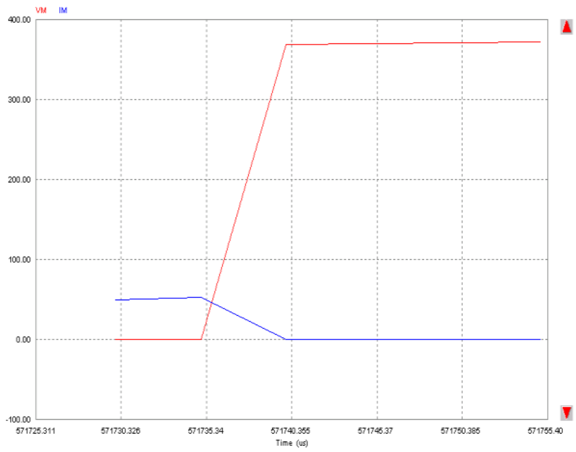

FIG. 23 TURN-OFF OVERLAP WAVEFORM

$$P_{dynamic} = V_{avg} \times I_{avg} \times t_{ol} \times f_s$$

$$P_{static} = V_{on} \times I_{avg} \times t_{on} \times f_s$$

$$P_{loss} = P_{static} + P_{switching}$$

It should be noted that if the converter is operating in DCM mode, then before further turn-on of the switch, the inductor current is reached to zero. So there will not be turn-on loss. But in CCM operating mode, since in turn-on instant for the switch, the current should be transferred form diode to the switch, the dynamic loss includes both turn-on/turn-off losses. The dynamic loss of input bridge diodes can be neglected

In this section, the sample calculation for failure rate for each component is presented:

a) ***Calculation of Failure rate λ_p for MOSFET (IXFH12N100Q/IXS) :***

V_n=1000V, Θ_{jc}=0.42° C/W, Θ_{ca}=1 $^\circ$ C/W

$T_c = T_a + \theta_{ca} \times P_{loss}$ = 27+1X69.163875
=96.163875

$T_j = T_c + \theta_{jc} \times P_{loss}$ = 96.163875+0.42 X 69.163875
= 125.2127

$\pi_T = \exp\left(-1925 \times \left(\frac{1}{Tj+273} - \frac{1}{298}\right)\right)$ = 5.08162

λ_b=0.012, π_E=6, π_A=10 , π_Q=5.5

$\lambda_p = \lambda_b \times \pi_Q \times \pi_E \times \pi_A \times \pi_T$
= 0.012 X 5.5 X 6X 10 X 5.08162 = 20.1232

b) Calculation of failure rate (λ_p) for Ouput diode:
V_n=1000V, Θ_{jc}=2°C/W, Θ_{ca}=1, P_{loss}=1.99056W

$T_c = T_a + \theta_{ca} \times P_{loss}$ = 27+1 X 1.99056 = 28.99056

$T_j = T_c + \theta_{jc} \times P_{loss}$ = 27+ 1X 1.99056 = 32.97168

$\pi_T = \exp\left(-1925 \times \left(\frac{1}{Tj+273} - \frac{1}{298}\right)\right)$ = 1.18329

λ_b=0.069, π_E=6, π_Q=5.5, π_C =1

$V_S = \frac{90}{500}$ =0.18 $\Rightarrow$, $\pi_S = V_S^{2.43}$ = 0.01549

$\lambda_p = \lambda_b \times \pi_Q \times \pi_S \times \pi_E \times \pi_T \times \pi_C$
= 0.069 X 5.5 X 0.015 X 6 X 1.183291 X 1
= 0.041735

c) Calculation of failure rate(λ_p) for Input Bridge:
V_n=1000V, Θ_{jc}=1.6 °C/W, P_{loss}=3.8808 W

$$T_c = T_a + \theta_{ca} \times P_{loss} = 27 + 1 \text{ X } 3.8808 = 30.8808$$

$$T_j = T_c + \theta_{jc} \times P_{loss} = 30.8808 + 1.6 \text{ X } 3.8808 = 37.09008$$

$$\pi_T = \exp\left(-1925 \times \left(\frac{1}{Tj+273} - \frac{1}{298}\right)\right) = 1.286413$$

λ_b=0.069, π_E=6, π_Q=5.5, π_C =1

$$V_S = \frac{304}{1200} = 0.2533 \Rightarrow \pi_S = V_S^{2.43} = 0.03554$$

$$\lambda_p = \lambda_b \times \pi_Q \times \pi_E \times \pi_C \times \pi_S \times \pi_T$$
= 0.069 X 5.5 X 6 X 1 X 0.03554 X 1.286413
= 0.104102

d) Calculation of failure rate (λ_P) for Inductor:

$$T_{HS} = T_A + 1.1 \times \Delta T = 27 + 1.1 \text{ X } 11 = 39.1$$

$$\lambda_b = 0.0016 \times \left(\frac{T_{HS} + 273}{329}\right)^{15.6} = 0.70282\text{m}$$

π_E=6, π_Q=20;

$$\lambda_p = \lambda_b \times \pi_Q \times \pi_E = 0.070282 \text{ X } 10^{-3} \text{ X } 6 \text{ X } 20 = 0.08433$$

e) Calculation of failure rate for Capacitor:

$$\Pi_{CV} = 0.34 \times C^{0.18} = 0.34 \text{ X } (917\mu)^{0.18} = 0.09653$$

π_E=2, π_Q=10

$$\lambda_p = \lambda_b \times \pi_Q \times \pi_E \times \pi_{CV}$$
= 0.13 X 10 X 2 X 0.09653 = 0.250978

f) Calculation of failure rate for Resistor:
π_R=1, π_E=2, π_Q=10, λ_b = 0.000066;

$$\lambda_p = \lambda_b \times \pi_Q \times \pi_E \times \pi_R = 0.00066 \text{ X } 10 \text{ X } 2 \text{ X } 1 = 0.0297$$

Therefore the total system failure rate will be:

$$\lambda_{system} = \sum_{n=1}^{N} \lambda_{part} = 20.634 \text{ (failures/ } 10^6 \text{ hours)}$$

$$\Rightarrow MTBF = \frac{1}{\lambda} = 48463.70$$

TABLE I CALCULATED POWER LOSS FOR EACH COMPONENT OF THE BOOST PFC RECTIFIER

Output Power	**800 W**			**1000W**			**1200W**		
Operating Mode	Peak	Average	Hysteresis	Peak	Average	Hysteresis	Peak	Average	Hysteresis
$P_{dynamic}$(MOSFET)	27.032292	49.614022	93.5101	28.7910	42.62004	73.416	33.787	40.68318	50.4336
P_{static}(MOSFET)	27.34746	43.9747	100.0123	27.81144	39.2316	78.46335	35.376875	43.3254	52.53623
$P_{dynamic}$(DIODE)	0.94956	1.2294	1.819272	1.270665	2.4239	3.889664	1.9836	1.9986	5.472
P_{static}(DIODE)	0.017835	0.0266568	0.051156	0.029445	0.030247	0.2752386	0.006961	0.00232	0.01152
Input Bridge	3.70128	3.7224	3.79104	3.84384	3.85176	3.86496	3.8808	3.91776	3.96

TABLE II CALCULATED POWER LOSS FOR BOOST PFC UNDER DCM AND CRM:

Output Power	**800 W**		**1000W**		**1200W**	
Operating Mode	**DCM**	**CRM**	**DCM**	**CRM**	**DCM**	**CRM**
$P_{dynamic}$(MOSFET)	258.44364	251.4707	229.7106	235.36	135.6885	152.9867
P_{static}(MOSFET)	0.1027628	22.2179	0.094374	26.668	0.02777	23.8866
$P_{dynamic}$(DIODE)	41.90355	128.1775	30.9852	141.3348	19.1568	166.6692
P_{static}(DIODE)	0.005655	0.16228	0.038627	0.108703	0.0054375	0.30942
Input Bridge	4.32432	5.16912	4.752	5.3724	5.7024	6.115824

TABLE III CALCULATED POWER LOSSES FOR MOSFET, OUTPUT DIODE AND THE INPUT BRIDGE:

Output Power	800 W			1000W			1200W		
Operating Mode	CCM	DCM	CRM	CCM	DCM	CRM	CCM	DCM	CRM
$P_{dynamic}$(MOSFET) Watts	71.4604	235.4625	238.05197	106.657	23.5172	318.1074	119.238	425.044125	451.6391
P_{static}(MOSFET) Watts	40.85928	0.1029	0.03659	19.36	5.4931	0.169814	17.768	0.25276	0.326604
$P_{dynamic}$(Output Diode) Watts	2.2758	60.732	76.650435	11.4468	12.2972	52.02252	2.5245	52.24275	56.25371
P_{static}(Output Diode) Watts	0.036125	0.005156	0.0019575	0.162	0.0971	0.018125	0.03912	0.0098	0.04902
P_{loss}(Input Bridge) Watts	2.5476	4.32432	4.7256	2.75616	4.9896	5.2008	2.86704	5.89248	6.0984

The failure rate of the elements is calculated based on [1], the measurement data, and the ambient conditions of the converter and its consisting materials. The results are shown in Table-IV, Table-V and Table-VI.

TABLE IV RESULTS OF RELIABILITY CALCULATIONS FOR DIFFERENT OUTPUT POWERS IN CCM OPERATING MODE FOR SINGLE SWITCH BOOST PFC:

Output Power	800 W			1000W			1200W		
Operating Mode	CCM	DCM	CRM	CCM	DCM	CRM	CCM	DCM	CRM
λ_p(MOSFET) (failure for 10^6 hours)	peak	average	hysteresis	Peak	Average	hysteresis	peak	average	hysteresis
λ_p(Output Diode) (failure for 10^6 hours)	15.376529	29.641633	88.85404	16.0416036	24.8069	60.5190	20.12232	25.6592	33.8496
λ_p (Input Bridge) (failure for 10^6 hours)	0.3631	0.4121	0.45275	0.065129	0.07387	0.08728	0.041735	0.04779	0.06247
λ_p(Input Inductor) (failure for 10^6 hours)	0.24109	0.25007	0.26585	0.14295	0.154851	0.16249	0.104102	0.110112	0.11347
λ_p(Output Capacitor) (failure for 10^6 hours)	0.25097	0.25098	0.232544	0.25097	0.250978	0.232544	0.25097	0.250978	0.232544
λ_p(Output Resistor) (failure for 10^6 hours)	0.06036	0.06036	0.06036	0.07145	0.07145	0.07145	0.08433	0.08433	0.08433
Total λ_p	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297
MTBF (hours)	16.321749	30.6448	89.8956	16.60180	25.3877	61.10247	20.634	26.18211	34.372114

TABLE V RESULTS OF RELIABILITY CALCULATIONS FOR DIFFERENT OUTPUT POWERS IN DCM AND CRM OPERATING MODES OF SINGLE SWITCH BOOST PFC:

Output Power	**800 W**		**1000W**		**1200W**	
Operating Mode	**DCM**	**CRM**	**DCM**	**CRM**	**DCM**	**CRM**
λ_p(MOSFET)(failure for 10^6 hours)	141.2463	154.563	117.03582	144.27654	50.8595	76.9641
λ_p(Output Diode) (failure for 10^6 hours)	3.8985	20.12467	0.65584	9.7153	0.07574	4.10102
λ_p(Input Bridge) (failure for 10^6 hours)	0.18448	0.214191	0.185059	0.202603	0.16015	0.174669
λ_p(Input Inductor) (failure for 10^6 hours)	0.18119	0.18119	0.181194	0.181194	0.181194	0.181194
λ_p(Output Capacitor) (failure for 10^6 hours)	0.06036	0.06036	0.07145	0.07145	0.08433	0.08433
λ_p(Output Resistor) (failure for 10^6 hours)	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297
Total λ_p	145.60053	175.1731	118.159063	154.4767	51.390614	81.535013
MTBF (hours)	6868.106	5708.639	8463.167	6473.468	19458.80	12264.669

TABLE VI RESULTS OF RELIABILITY CALCULATIONS FOR DIFFERENT OUTPUT POWERS IN CCM, DCM AND CRM OPERATING MODES OF INTERLEAVING TOPOLOGY:

Output Power	**800 W**			**1000W**			**1200W**		
Operating Mode	CCM	DCM	CRM	CCM	DCM	CRM	CCM	DCM	CRM
λ_p(MOSFET)(failure for 10^6 hours)	38.3430	128.4287	130.5580	45.45882	195.2066	195.5812	51.6007	300.7802	327.66715
λ_p(Output Diode) (failure for 10^6 hours)	0.10022	1.01522	1.57229	0.29053	1.38784	1.56465	0.30083	2.5070	2.930126
λ_p(Input Bridge) (failure for 10^6 hours)	0.1034	0.124433	0.138765	0.14213	0.169239	0.18064	0.173112	0.20993	0.22177
λ_p(Input Inductor) (failure for 10^6 hours)	0.25495	0.181194	0.181194	0.254948	0.181194	0.181194	0.254948	0.181194	0.181194
λ_p(Output Capacitor) (failure for 10^6 hours)	0.06041	0.06041	0.06041	0.071314	0.071314	0.071314	0.084338	0.084338	0.084338
λ_p(Output Resistor) (failure for 10^6 hours)	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297
Total λ_p	38.89168	129.8396	132.54036	46.24744	197.0459	197.60873	52.443628	303.7923	331.11427
MTBF (hours)	25712.44	7701.81	7544.871	21622.818	5074.959	5060.505	19068.09	3291.722	3020.1053

V. DISCUSSION OF RESULT

Considering table IV, V, VI the following points can be concluded.

1. The Boost Converter has highest reliability in CCM operating mode than in DCM and CRM.

2. Switches have highest failure rate in DCM and CRM modes than CCM mode. Since in DCM and CRM modes the peak and rms values of current are higher that results in higher current stress on switches in this mode. Therefore failure rate is higher in CRM and then DCM compared to CCM.

3. The results concluded for single switch boost PFC are true for interleaving configuration also. But the reliability of interleaved topology is much lesser compared to the single switch boost PFC because of the presence of two inductors, two diodes and two MOSFETs.

References

[1] MIL-HDBK-217, "*Reliability Redaction of Electronic Equipment*".
[2] "*Reliability aspects on Power Supplies*", Design Note 002 EN/LZT 14600 RIA (C Ericsson Microelectronics AB, April
[3] Brett A. Miwa david, M. Otten martin, F. Schlecht, "*High Efficiency Power Factor Correction Using Interleaving Techniques*".
[4] Dao-Shen Chen, Jih-Sheng Lai, "*A Study of Power Correction Boost Converter Operating at CCM-DCM Mode*"
[5] B. Abdi, M. B. Menhaj, L. Yazdanparast, J. Milimonfared, "*The Effect of the Transformer Winding on the Reliability of Switching Power Supplies*", IEEE, 2006.