JOINT INSTITUTE FOR NUCLEAR RESEARCH

Veksler and Baldin Laboratory of High Energy Physics

FINAL REPORT ON THE INTEREST PROGRAMME

THERMAL OPTIMIZATION OF THE "INTELLIGENT POWER DISTRIBUTOR" USING THE CFD METHOD

(Heat Transfer Simulation for the updated version of IPD)

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ABSTRACT

Electrical and electronic components are the essential part of any modern-day device. However, due to inefficiency in operation leads to dissipation of heat which leads that has many side-effects like deterioration of life-span, derating and accidental failures. The same is true for the Intelligent Power Distributor (IPD) that powers the NICA-MPD. The heat dissipation of components inside the IPD is determined and a heat simulation is carried out. Operational temperature exceeds the safe limit for many components and derating is observed as well. To mitigate these issues, a small-sized cooling fan in installed and a second-time simulations shows significant reduction in temperatures. Further study on effects of heat dissipation and improved cooling approaches is advised.

INTRODUCTION

Thanks to the modern-day electronics that power the essentials, it is now possible to accomplish tasks like never-before. Be it making calls on your smartphone or carrying out extremely complex experiments through the equipments at the JINR laboratory, everything is powered by electricity and there are several electronic components in play. Just like there's a power supply/distribution unit for your computer or TV, The Multi-Purpose Detector (MPD) platform, one of the most essential parts of the Nucleotron (NICA) project is the NICA-MPD project has its electric power managed by the Intelligent Power Distributor (IPD). There are several components like MCBs, charge controllers, battery modules, CPU units etc that are involved in power management and supply.

However, owing to the universal fact that no device can be 100% efficient, there is always some loss of electrical power associated with the operation of every device and component. Alongside others forms, the power loss often comes out as heat making heat management a very important aspect of any electrical/electronic design. It is even more essential for circuits and systems that are enclosed inside a box or enclosure where ventilation of generated heat

Though it isn't noticeable at the first glance, power dissipated by the electronic components in the form of heat can often add up to a sizeable value that leads to several critical issues. The temperature of the unit increases by several degrees during operation and this significantly affects the performance of the components, both in short-term and long-term. It may also happen that temperature rises above the safe operating window of those components leading to breakdowns, short-circuits, fire accidents or other mishaps. One must be aware that the lifespan of all our dear electronic devices comes to stake if we over-use them and this is because the heat generated by components is detrimental and needs to be 'managed' properly. A general fact says [1]

The Intelligent Power Distributor (IPD) of the NICA-MPD (whose assembly/design is discussed later) houses several electrical components inside an enclosure. To ensure that things work out perfectly over the long run and there is no failures during operation, it is ideal to use the power of heat simulations and CFD (Computational Fluid Design) to build and visualize the IPD model and heat generation scenario during operation. Out of the several softwares and computational tools available, Autodesk CFD 2021 (student edition) and Autodesk Inventor Professional 2019 (student edition) were used in this study.

GOALS UNDER THIS PROJECT

The following are the goals under this project of Heat Transfer Simulation for the Upgraded Version of IPD –

1. Study the heat distribution & temperature profile of the existing IPD configuration (due to temperature rise)
2. Study the immediate problems caused by this (derating)
3. Check whether the temperature stays in safe operating window or not
4. Create an upgraded configuration with fans, blowers for cooling – size/type of fan, position
5. Study the long term impacts on lifespan and ways to enhance it.

SCOPE OF WORK IN THIS PROJECT

To start with, it’s essential to build a 3D model of the system based on the specifications and geometry of the involved components. Then, the heat generated by the components (in Watts) is to be calculated based on the technical specifications of each component (power ratings, operation efficiency). Based on this, a simulation can be performed to visualize the heat distribution and temperature gradient across the assembly. The main aim of this task is to determine what can be the maximum temperature reached for each component and whether it falls inside the safe window. The temperature rise inside the assembly is also to be checked. Moreover, its desirable to see if there is any immediate depreciation in performance of components (known as derating) due to increase in temperature.

This being said and done, the main challenge of this study is to determine optimal approaches or methods to prevent heating of components. This can be done by installation of fans or blowers (active cooling) and also by changing the configuration of the components installed inside the enclosure. The relative position and the orientation of components can affect the overall heat distribution while operation and it is worthwhile to carry out optimization to find out the best geometry. However, the new geometries mayn’t be easy to implement as the enclosure comes with a certain build and design from the manufacture. Thus, active cooling approach using fans/blowers is good to start with.

METHODS

The various methods by which this study was carried out is described in this section.

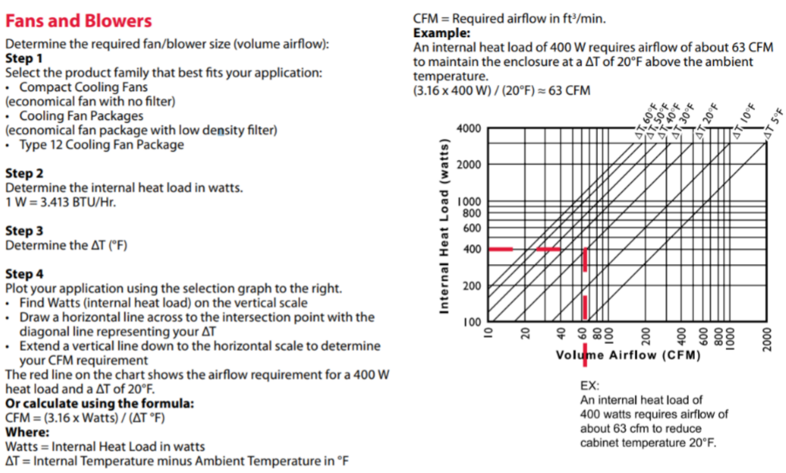
1. DETERMINING HEAT DISSIPATION FOR ALL THE COMPONENTS

Component Name	Heat Generation (W)	Quantity (No)	Reference
Siemens S7-1200 CPU 1214C (6ES7214-1AG40-0XB0)	12	1	
Siemens S7-1500 CPU 1515F (6ES7515-2FM01-0AB0)	6.3	-	
SIMATIC S7-1200, Digital output SM 1222 (6ES7222-1BH32-0XB0)	2.5	4	
SIMATIC S7-1500, DIGITAL OUTPUT MODULE (6ES7522-5EH00-0AB0)	3.8	-	
WAGO 787-1671	not known	1	
MeanWell DRC-100A	14.4	1	
Meanwell DRC-100 B	11.94	-	
MeanWell DDR 15 G 12	4.2	1	
Legrand MCB TX³ 10000 1P 16A	2	16	
Legrand MCB TX³ 10000 1P 25A	2.7	-	
Legrand MCB TX³ 10000 1P 63A	5.5	-	
Legrand MCB TX³ 10000 3P 16A	6	-	
Legrand MCB TX³ 10000 3P 25A	8.1	-	
Legrand MCB TX³ 10000 3P 63A	16.5	2	
Legrand Motorised control DX³ - 24-48 V~/= - standard	0	-	
Total Heat Dissipated (in Watts)		105.6	

Table 1 shows the list of electrical components used in the Intelligent Power Distributor. The list shows name of the components, quantity for each component, power dissipation (in form of heat, Watts) and reference to the manufacture-supplied technical specifications. (The placement of some components is either not known or they aren't required for the simulation study at this stage so their quantity isn't mentioned).

2. CALCULATION OF FAN SIZING AND SPECIFICATIONS FOR COOLING

Based on the summation value of heat generated, we can calculate the specifications of a fan/blower that is required for mitigating the heat load.



Based on the fan-sizing guide, the minimum CFM of the fan = 33.37

(Heat load = 105.6 Watts for the enclosure and desired operation temperature is 10 degrees above the operating temperature).

For this study, the physical dimensions of the fan are most important as it has to be practically installed inside the enclosure. A commercially available circular DC cooling fan is taken for simulation. The specifications are as follows –

- **Dimensions: 17.2 cm x 17.2 cm x 5.1 cm**
- **Air Flow of fan (maximum): 8.65 m^3/min i.e. CFM ~ 300**
  (It was verified that minimum CFM of the fan is above than the calculated value).
- **RPM (maximum): 4000**

It is to be noted that the above calculation is based on the assumption that components are closed inside an enclosure which has no openings for ventilation (and so all heat is trapped inside). The exact fan specifications (sizing, power, speed etc) will also depend on some factors like density of air and humidity content in air (that will vary on daily and seasonal basis).

The distribution of heat inside the enclosure is the most important aspect to deal with. The dissipated heat is concentrated in some spots and it may happen that air from fan doesn't adequately blow over those spots owing to the miniature air flow channels created inside the enclosure by the openings in the enclosure. Thus, CFD simulation of air flow by fan is also to be carried out along with the simulation of power dissipation of components (as done earlier).

3. HEAT SIMULATION PRIOR TO FAN INSTALLATION (PRIMARY SIMULATION)

A heat simulation of the 3D geometry before the installation of cooling fan (referred to as primary simulation in this study) was carried out using Autodesk CFD 2021. Component-wise analysis can be found out in the subsequent sections.

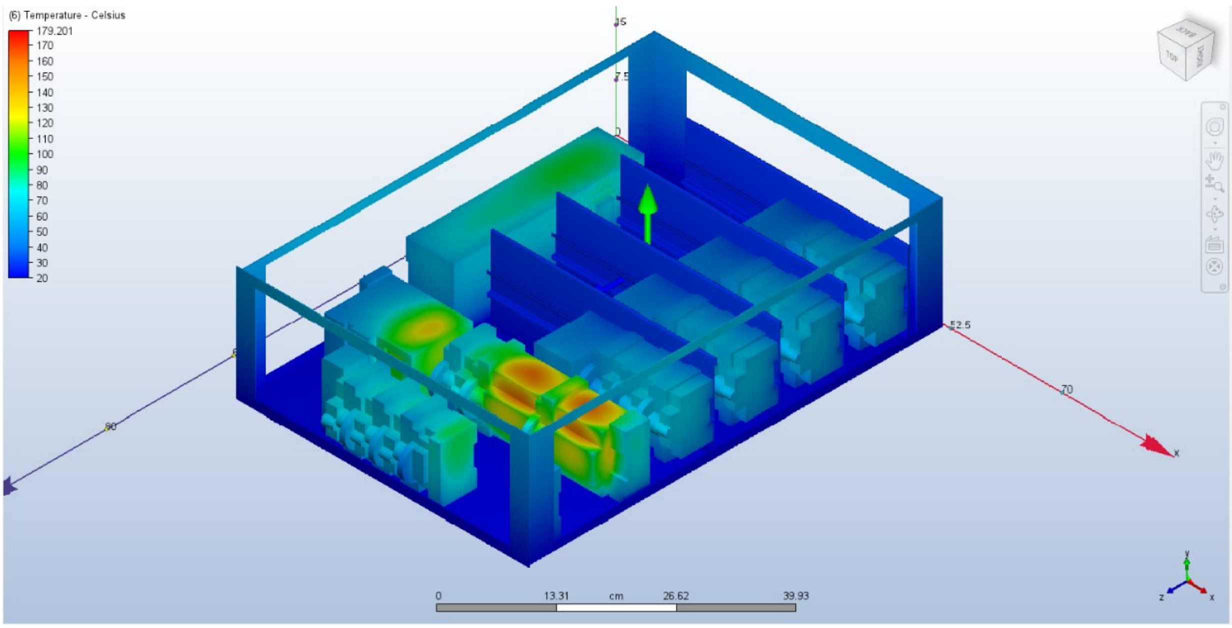


Figure 1 shows the heat distribution after primary simulation was carried out. We can clearly see that operational temperature is high for many of the components.

4. HEAT SIMULATION AFTER INSTALLATION OF COOLING FAN (SECONDARY SIMULATION)

A heat simulation of the 3D geometry after the installation of cooling fan (referred to as secondary simulation in this study) was carried out using Autodesk CFD 2021. Component-wise analysis can be found out in the subsequent sections.

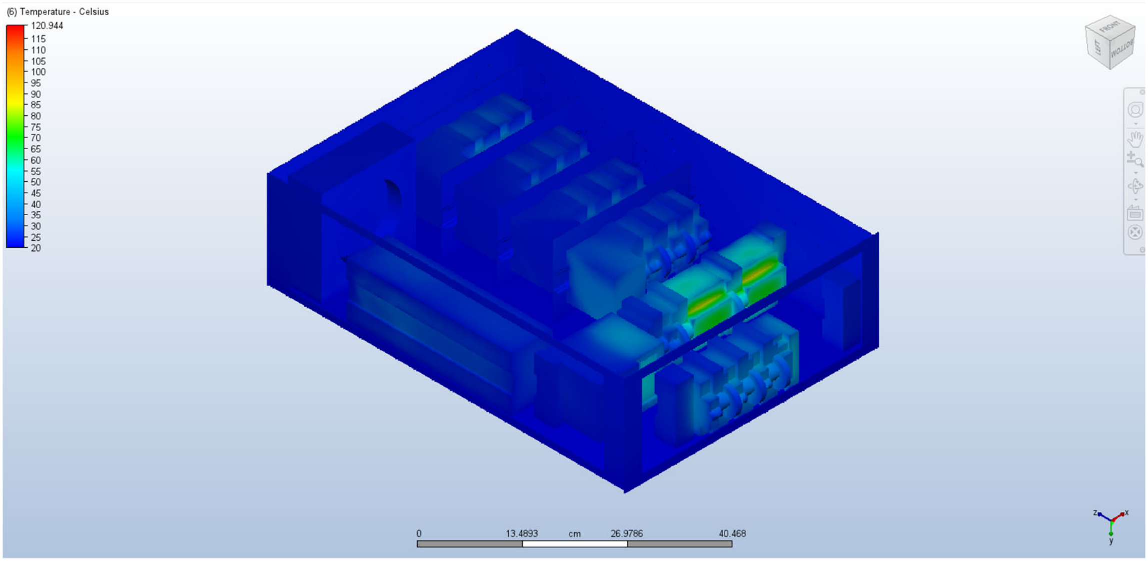


Figure 2 shows the heat distribution after secondary simulation was carried out. It is evident that there has been significant reduction of heat even by installation of one single small-sized fan.

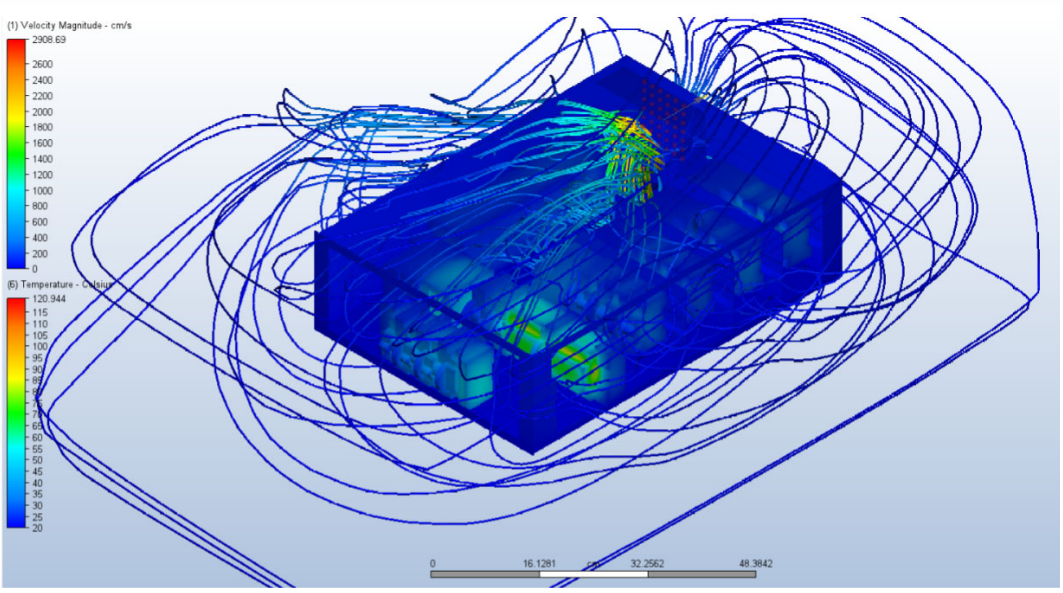


Figure 3 shows velocity streamlines dictating the flow of air inside IPD in secondary simulation (post addition of fan).

OBSERVATIONS AND RESULTS

1. IMPACT OF HEAT GENERATION ON COMPONENTS (BASED ON PRIMARY SIMULATION)

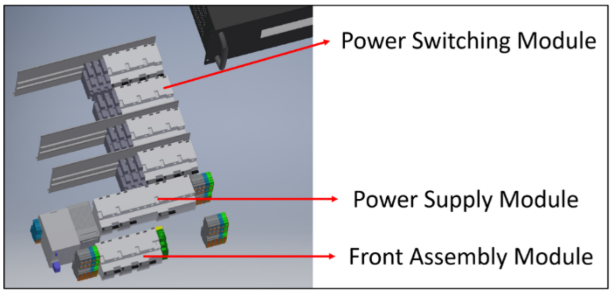
Before we take up any challenge and work towards its solution, it's advisable to analyse all possible problems in detail. It is known that increase in temperature leads to decrement in performance of the electronic components as they don't perform at their specified power rating. The rating of electrical components is done at the standard ambient temperature (ie 25 – 30 Celsius) but the rating decreases with increase in ambient temperature during operation. This is known as derating.

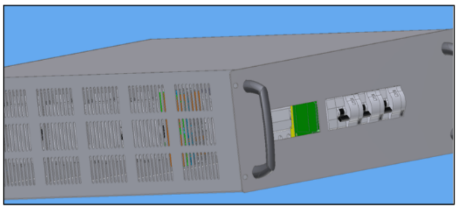
From the results of primary simulation, the maximum temperature (that is reached during operation) is determined for each component and corresponding derated value is found out (from technical specifications of that component).

It is evident that most of the components perform at a sub-standard rating or capacity due to increased temperatures and this leads to several impacts. A plausible solution to this is to ensure cooling to properly mitigate heat. And for this, secondary simulation was performed.

2. IMPACT OF COOLING (BASED ON SECONDARY SIMULATION)

Active cooling by use of a fan was decided to be a suitable approach for mitigating heat and a simulation was carried out by adding the cooling fan to the previous geometry. As we notice, there has been a significant reduction in maximum temperature reached by the use of cooling fan.





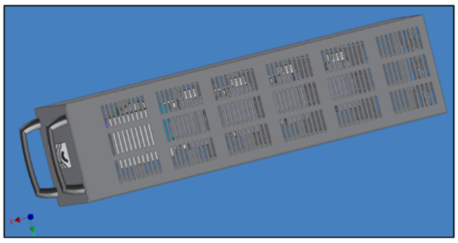


Figure showing the overall geometry and assembly of the IPD module (before the installation of fan). Notice that position of few components isn't determined so some space is left towards the rear. Installation of cooling fan is possible at that spot. However, it is to be seen if the air from the fan can be properly to all the modules esp. the Front Assembly Module.

Table 2 shown in the following page gives a detailed component-wise analysis of temperatures for both the simulation and also highlights the reduction obtained by installation of fan.

		Before Fan Installation				After Fan Installation				Reduction in Max Temp		Reduction in Avg Temp	
Sl No	Name of the component	Min Temp	Max Temp	Avg Temp	Derated Value	Min Temp	Max Temp	Avg Temp	Derated Value	Delta T	% Reduction	Delta T	% Reduction
1	SIMATIC S7-1200, Digital output SM 1222_cfd:4@CPU_module_cfd:1	20.000	80.825	59.983	-	20.000	39.823	31.104	-	41.002	50.730	28.879	48.146
2	SIMATIC S7-1200, Digital output SM 1222_cfd:3@CPU_module_cfd:1	20.000	83.263	62.100	-	20.000	40.541	31.514	-	42.723	51.310	30.586	49.253
3	SIMATIC S7-1200, Digital output SM 1222_cfd:2@CPU_module_cfd:1	20.000	76.467	55.024	-	20.000	38.350	28.433	-	38.117	49.847	26.591	48.326
4	SIMATIC S7-1200, Digital output SM 1222_cfd:1@CPU_module_cfd:1	20.000	91.833	65.360	-	20.000	46.373	32.848	-	45.461	49.503	32.512	49.743
5	SIMATIC S7-1200, CPU 1214C:1@CPU_module_cfd:1	20.000	98.966	70.001	-	20.000	50.321	34.719	-	48.646	49.154	35.282	50.402
6	Legrand408887_cfd:1@FrontModule_cfd:1	36.125	77.351	66.904	Temp. above limit	23.395	43.226	35.910	15.400	34.126	44.118	30.994	46.326
7	HDR-15_cfd:1@FrontModule_cfd:1	31.000	95.334	80.394	Temp. very high	23.500	62.250	49.692	-	33.084	34.704	30.703	38.190
8	Legrand408887_cfd:3@FrontModule_cfd:1	45.194	81.977	71.876	Temp. above limit	26.279	50.891	42.668	14.700	31.087	37.921	29.209	40.637
9	Legrand408887_cfd:2@FrontModule_cfd:1	46.847	81.856	72.100	Temp. above limit	25.522	50.002	41.908	14.700	31.854	38.915	30.191	41.874
10	Legrand408887_cfd:3@PhaseSwitchingModule_cfd:4	27.070	67.056	56.464	13.500	21.366	35.529	29.325	15.400	31.527	47.016	27.140	48.065
11	Legrand408887_cfd:2@PhaseSwitchingModule_cfd:4	26.818	67.269	55.849	13.500	21.719	40.706	33.062	15.400	26.563	39.488	22.786	40.800
12	Legrand408887_cfd:1@PhaseSwitchingModule_cfd:4	26.331	62.928	52.282	14.100	21.836	40.003	32.696	15.400	22.925	36.430	19.586	37.462
13	Legrand408887_cfd:3@PhaseSwitchingModule_cfd:3	26.463	66.445	55.654	13.500	21.421	37.445	30.939	15.400	29.000	43.644	24.716	44.409
14	Legrand408887_cfd:2@PhaseSwitchingModule_cfd:3	26.330	66.903	55.409	13.500	21.419	40.277	32.281	15.400	26.626	39.798	23.128	41.741
15	Legrand408887_cfd:1@PhaseSwitchingModule_cfd:3	25.968	62.674	51.925	13.500	21.175	38.304	30.957	15.400	24.369	38.883	20.968	40.382
16	Legrand408887_cfd:3@PhaseSwitchingModule_cfd:2	26.788	67.243	56.229	13.500	21.610	37.659	31.043	15.400	29.583	43.995	25.185	44.791
17	Legrand408887_cfd:2@PhaseSwitchingModule_cfd:2	26.567	66.784	55.465	13.500	22.130	43.618	35.599	15.400	23.166	34.688	19.867	35.818
18	Legrand408887_cfd:1@PhaseSwitchingModule_cfd:2	26.113	62.821	52.047	14.100	22.190	41.714	34.759	15.400	21.107	33.599	17.288	33.216
19	Legrand408887_cfd:3@PhaseSwitchingModule_cfd:1	27.563	70.273	58.601	13.500	21.667	38.528	31.853	15.400	31.745	45.173	26.747	45.643
20	Legrand408887_cfd:2@PhaseSwitchingModule_cfd:1	27.224	69.051	57.052	13.500	22.132	42.956	34.661	15.400	26.095	37.791	22.391	39.247
21	Legrand408887_cfd:1@PhaseSwitchingModule_cfd:1	26.667	64.641	53.643	14.100	22.383	42.528	34.858	15.400	22.114	34.210	18.785	35.019
22	Wago_787-1671_cfd:1@PowerSupplyandDistributionModule_cfd:1	26.812	112.565	61.004	Temp. very high	20.432	67.299	30.046	-	45.266	40.213	30.958	50.748
23	DRC100A_cfd:1@PowerSupplyandDistributionModule_cfd:1	40.552	138.420	106.981	Temp. very high	22.457	85.925	57.163	-	52.495	37.925	49.818	46.567
24	Legrand411695_cfd:1@PowerSupplyandDistributionModule_cfd:1	49.016	176.860	137.489	Temp. above limit	23.313	118.265	80.619	Above limit	58.595	33.131	56.870	41.363
25	Legrand408887_cfd:1@PowerSupplyandDistributionModule_cfd:1	44.629	98.880	81.343	Temp. above limit	26.188	44.315	34.520	15.400	54.565	55.183	46.823	57.562
26	Legrand411695_cfd:2@PowerSupplyandDistributionModule_cfd:1	59.276	179.201	139.968	Temp. above limit	25.134	120.944	84.339	Above limit	58.257	32.509	55.629	39.744
									Average Values =	**35.773**	**41.534**	**30.140**	**43.672**

CONCLUSION:

Electronic and electrical components are the essential part of every modern-day system or device. However, all such components dissipate power in the form of heat owing to inefficiency. Heat dissipated leads to rise in temperature during operation and this is a major issue when components are boxed inside an enclosure with restricted or no ventilation. Based on the concepts of this study and works carried out, the following conclusions can be drawn –

1. The study for thermal management of Intelligent Power Distribution (IPD) system is carried out in this work as heat management & mitigation is an essential step to designing of any electrical circuit or system.

2. The power loss was calculated for each component. The power loss value may be found directly in the technical specifications or can be calculated from the other values given (input, output, efficiency etc).

3. The available 3D model of the IPD system was simplified and a heat simulation (referred to as primary simulation in this study) was carried out based on the power loss values. The minimum/maximum temperatures and heat distribution was obtained.

4. The temperature for many of the components goes significantly high (sometimes beyond the safe limit). Also rise in temperature leads to derating or reduction in performance or capacity. This is described in Table 2

5. Out of several approaches possible for mitigating heat, active cooling by the use of a cooling fan is a plausible approach. The calculation for fan sizing is done and a simulation is carried out (referred to as secondary simulation) with the fan installed.

6. A significant reduction in temperature values is noticed. The analysis of this reduction is described in Table 3. A average reduction of maximum temperature by 35.773 ° Celsius (i.e 41.534 %) is observed.

7. By the installation of just a single small size fan, thermal management of heat enclosure is achieved by a great deal.

SCOPE FOR FUTURE WORK:

1. The power loss of most of the components has been determined except for 1-2 components. Also, some components may have a variable power loss or power loss in forms other than heat. So, the calculation procedure can be revalidated and the final values can be rechecked.

2. The simulation procedure (both for primary & secondary simulation) can be improved in various aspects, say in terms of simplification of geometry, improving meshing & material selection. Time elapsed and computing resource consumption is also to be taken care of.

3. The current study has focused on the use of a single small-sized fan only. Distribution of fan from air seems to be slightly uneven and a single fan can be inadequate for cooling.

4. A few more fans or fans of bigger size can be installed properly to manage heat and this could be the immediate steps in future study. The model geometry has to be checked simultaneously for this

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