Intelligent Cooling System Design for Higher end Power Electronics Convertors used in Wind Turbine Generation Systems with Live Temperature Monitoring and Control Applications

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***Abstract*:-The famous quote says that "Prevention is better than cure".Thus in the wind energy systems, the development of unnecessary heat from Electronics parts like power converters result in dreadful fire accidents and disasters. In general the additional cooling system instead of natural air cooling system is required for high power converters used in Wind Turbines. Now a days a separate unit with compressor based cooling system or two phase cooling system is used.Even though the performance of this system is satisfactory their size,power requirements,maintenance and possibility to fire made those system as less efficient one. So we have designed an appropriate system using compressor less cooling units composed of Thermo-electric coolers (TEC) so called Peltier modules. The conventional system excavates the heat only after the system reaches enormous temperature levels. In our system the surface of heat dissipating bodies are sectorized and the temperature of those portioned surfaces are monitored completely. when a continuous rise in temperature of a surface is detected, the cooling system is automatically engaged. Which shows that this system not only acts as heat excavation system after the temperature reaches to dangerous extends, but also it intelligently monitoring the temperature level and employ active cooling over the surfaces at prompt time instants.**

AGENDA:- INNOVATIVE COOLING PROCESS USING TEC MODULES.

Basic block diagram.

2.2.Components of block diagram.
Composed Modules.

The Thermo-electric coolers(TEC-peltier modules).

2.211.Working principles of TEC.
2.212.Seebeck effect.
2.213.Peltier effect.
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Temperature sensor and its control.

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PLC-(Programmable Logic Controller).
2.7.Forecasting system.
Organized working of over all system.

Practically Analyzed Data Using Experimental Module and analytical design for FUJI FILM-IGBT cooling system

2. REFERENCES

1. POWER ELECTRONIC CONVERTERS IN WIND ENERGY SYSTEMS:-

Converters are used in wind energy systems for several reasons. Converters used today are power electronic devices.Thus the technology develops and the cost drops, the importance of power electronic devices in wind turbine systems increases rapidly. Power converters are used in variable-speed wind turbines, in generator starters and in isolated networks. When applying power electronic converters to wind turbines, most of engineers have chosen a solution based on the two-level voltage source converter, combined with a doubly fed induction generator. This topology consists of two power converters, connected by an energy storage element. An alternative to the conventional converters is the matrix converter. The matrix converter might become a competitive alternative to the conventional back-to-back voltage source converter. The matrix converter preforms a direct AC to AC conversion, by which the large energy storage element of conventional converters is avoided. Due to the lack of energy storing element, it is expected to have a more compact design.

HEAT GENERATION BURDEN AND COOLING OF CONVERTERS:-

One of the major drawbacks of using power electronic converter systems is generation of High heat energy. The power electronic components are made up of semiconductors, Thus the size of switch used in the converter is small but it excretes high heat energy with respect to their operating power. The heat developed in switches lead to damage it self. The plastic casing of those switches increases the possibility of burning. Hence the heat generation on power electronic switches are a big burden in now a days.The conventional cooling system used are HEAT SINKS, EXHAUST FAN SYSTEMS,SINGLE PUMP COOLING SYSTEM etc. In now-a-days TWO PHASE COOLING
SYSTEM is the most advanced cooling system employed for cooling electronic components..Let us discuss about it.

PUMPED SINGLE STORAGE OR TWO PHASE COOLING:-

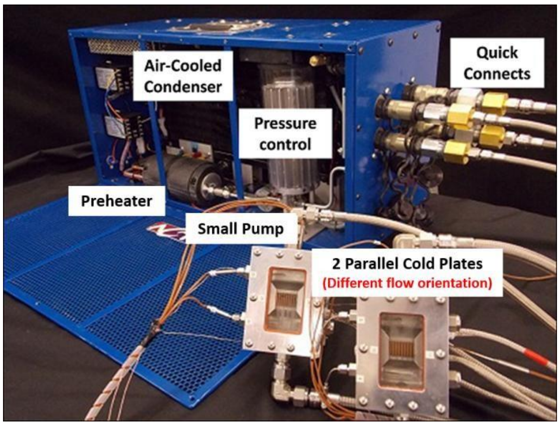
Pumped single or two phase cooling is generally used to remove and dissipate heat from high-power heat sources such as electronics and lasers, or when the thermal energy must be transferred a significant distance between the heat source and the heat sink. Pumped single phase cooling is commonly used today in power electronics equipment, where the heat fluxes are relatively low and/or temperature uniformity is not required.

WORKING PRINCIPLE OF TWO PHASE COOLING SYSTEMS:-

In pumped two phase cooling systems, heat is transferred by the evaporation and condensation of a portion or all of the working fluid. Typically, a liquid near saturation is pumped into the cold plate, where it starts to boil, cooling the electronics and storing the energy in the latent heat of the fluid. The two phase (liquid and vapor) fluid then flows to the condenser, where the heat is removed, condensing the vapour, so that a single phase (liquid) exits the condenser, and the cycle repeats.

LAYOUT OF TWO PHASE COOLING SYSTEM :-

The basic layout of a pumped two phase cooling system is similar to a pumped single phase system, except that a two phase reservoir is used to accommodate changes in fluid volume, rather than the accumulator that is used in a single phase system. An example pumped two phase system is shown in below Figure, where quick connects allow cold plates (and associated electronics) to be swapped out without the need to drain and recharge the system. Flexible lines allow the cold plates to be tested in any orientation, and at different elevations.



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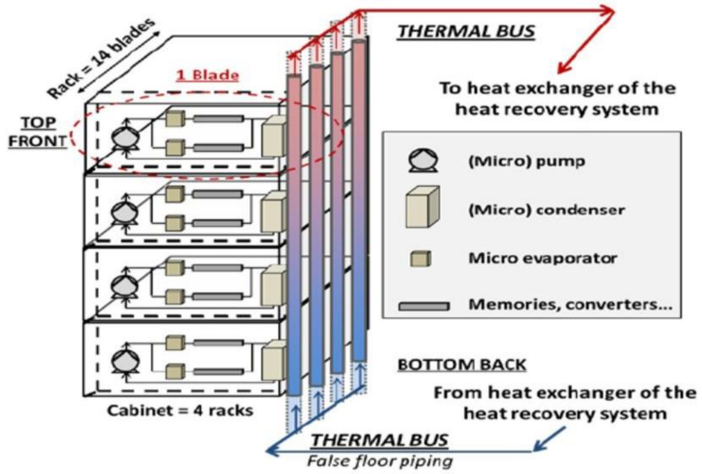
A TWO PHASE COOLING SYSTEM LAYOUT

SCEMATIC ARRANGEMENT



The cold plates (heat sinks) are the two evaporators in the front of system, with a transparent top plate. For the right evaporator, the single phase flow enters from the bottom, with a two phase mixture exiting the top of the cold plate. Some electronics cooling applications have large numbers of parallel electronics boards, where it is desirable to apply electrical power and cool an arbitrary number of boards, without having to adjust the flow to each board. This is easily accommodated with a pumped two phase cooling system, where large numbers of cold plates can be cooled in parallel (series flow is not generally used when temperature uniformity is important, so that each cold plate has the same entrance conditions).

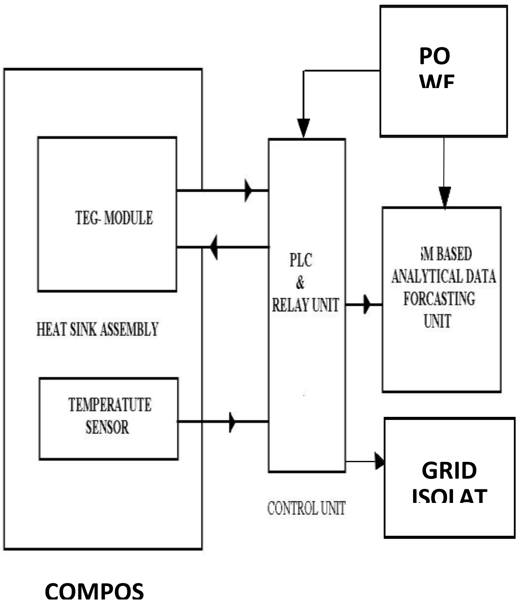
DISADVANTAGES OF TWO-PHASE COOLING SYSTEM:-

- This system requires much maintenance.
- Coolant is heavily toxic.
- The components of this system requires large space.
- The cost of the over all system is moderately high.
- Difficult to install.

2. INNOVATIVE COOLING PROCESS USING TEC MODULES.

According to the necessity of cooling in several fields such as electronics ,automotive , and photo-voltaic , Thermo-electric coolers (TEC) have become widespread in the last decades.
Thermo-electric coolers contain a number (N) of n-p Thermo-electric doped couples made of semiconductor material inserted between two thermally conducting and electrically insulating ceramic plates.Thus the TEC are capable of high efficient cooling
They are used for applications that require heat removal ranging from milliwatts to several thousand watts. They can be made for applications from micro to macro applications.
Thermo-electric coolers are used in many fields of industrial manufacturing and require a through performance analysis as they face the test of running thousands of cycles before these industrial products are launched to the market.
The modules are available for various power and temperature ratings hence it gives broad instrumentation values.
In our systems the modules are constructed with supporting and measuring components like Heat sink ,Temperature sensor and moisture absorbing foam.
This system give individual authentic cooling over different elements or surface placed with it.
The TEC module cooling may be seems in-effective for cooling large systems, this black dot criteria is our positive theme because, it is not necessary to cool all the parts in a system, it's smart to cool the exact cooling spot even while the continuous temperature is detected.
Thus this system efficiently monitors the temperature of profound parts and intelligently cools and control efficiently.

BLOCK DIAGRAM:-



2.2COMPONENTS OF BLOCK DIAGRAM

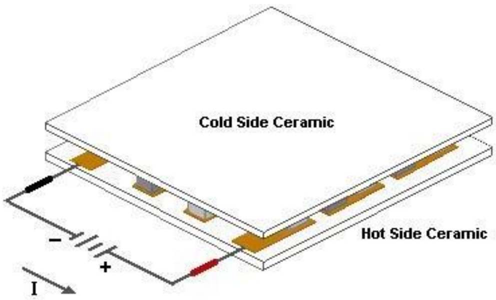
COMPOSED MODULES:-

The composed module consists of TEC module, Heat sink assembly and temperature sensor. This module is placed in the surface of heat dissipation bodies. The number of modules required for the particular body is determined by the heat dissipation factor of material used and surface area of the heat dissipating body. They are specially designed with foam envelope layer for absorbing the moisture content if developed any due to high cooling. The modules has extension connecting wire leads for placing the temperature sensor in suitable places of the portioned sector surface.

THE THERMO-ELECTRIC COOLERS

(TEC-PELTIER MODULES):-

Thermo-electric power generator is a solid-state semiconductor device that either convert heat directly into electricity or transform electrical energy into thermal power for heating or cooling. Such devices are based on Thermo-electric effects involving interactions between the flow of heat and of electricity through solid bodies.



(TYPICAL STRUCTURE OF A TEC)

2.211.WORKING PRINCIPLE OF PELTIER MODULE:-

The working of the peltier module is typically explained by the two basic effects as given below.Those two effects are completely inverse to each other, thing is both of them are applicable for TEC.

- Seebeck effect
- Peltier effect.

2.212..SEEBECK EFFECT

It is defined as the the phenomenon in which the electrical current is produced in a circuit containing two or more different metals. When the junctions between the metals are maintained at different temperature levels.This was discovered by German physicist Thomas Seebeck (1770-1831). Seebeck initially believed that it was due to the magnetism induced by the temperature differences and he called the effect as thermo-magnetic effect. However Danish physicist Hans Christian Orsted realized that it's an electrical current that is induced, which because of Ampere law deflects the magnetic element.
The Seebeck Effect can help us calculate the electromotive field generated by a device. This can be done by using the Seebeck Coefficient. The Seebeck Coefficient of a material is the measure of the magnitude of the increased Thermo-electric voltage in response to the temperature differences in a given material. Using the Electromotive force, we can also calculate the current density of the Thermo-electric material.

$$E_{emf} = -S\Delta T$$

Where as;

S-Seebeck Coefficient

T-temperature differences in a given material

$$J = \sigma(-\Delta V + E_{emf})$$

Here,

J - current density

σ - conductivity of the conductor.

2.213.PELTIER EFFECT

The Peltier Effect was discovered by the French physicist Jean Charles Athanase Peltier in 1834. The Peltier Effect is the development of heating or cooling at an electrified junction of two dissimilar conductors. When the current is made to flow through the junction between two conductors, heat may be added or removed at the junction. The Peltier heat generated at the junction per unit time is where $\prod_A$ and $\prod_B$ are the Peltier coefficients.

$$Q = (\prod_A - \prod_B) I$$

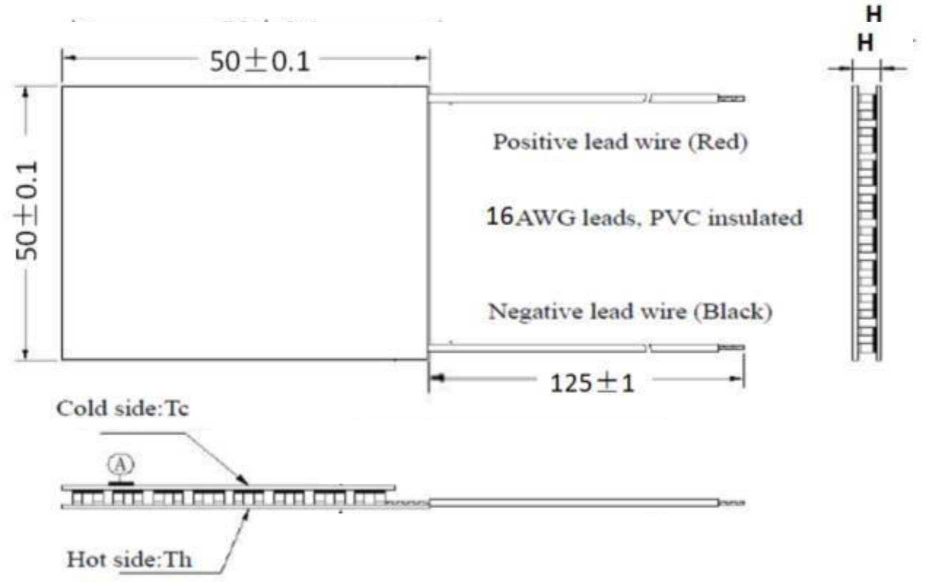
Here, A and B signify the two ends of the conductors, while I is the electric current. The Peltier coefficients represent how much heat is carried per unit of charge. Since charge must be continuous across a junction, the associated heat flow will develop a discontinuity if $\prod_A$ and $\prod_B$ are different. The Peltier Effect can be considered as the back-action counterpart to the Seebeck Effect: if a simple Thermo-electric circuit is closed, then the Seebeck Effect will drive a current, which in turn (by the Peltier effect) will always transfer heat from the hot junction to the cold junction.

PELITIER-MODULE USED IN OUR SYSTEM:-

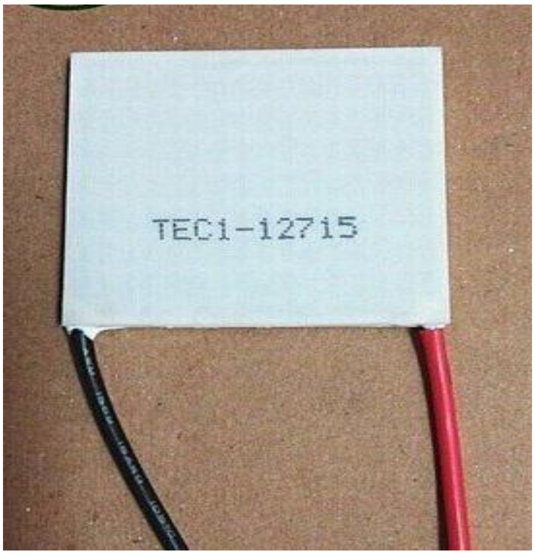
TEC1-12715 - HIGHER EFFICIENT COOLING MODULE SPECIFICATION OF THERMOELECTRIC MODULE

Th (ºC)	50	Hot side temperature at environment: dry air, N_2
DT_{max} (ºC)	79	Temperature Difference between cold and hot side of the module when cooling capacity is zero at cold side
U_{max} (Voltage)	17.2	Voltage applied to the module at DT_{max}
I_{max} (amps)	15.0	DC current through the modules at DT_{max}
Q_{Cmax} (Watts)	164.2	Cooling capacity at cold side of the module under DT = 0 ºC
AC resistance (ohms)	0.88	The module resistance is tested under AC
Tolerance (%)(+OR-)	10	For thermal and electricity parameters

DIMENSIONS OF TEC1-12715:-



(ACTUAL IMAGE OF MODULE)



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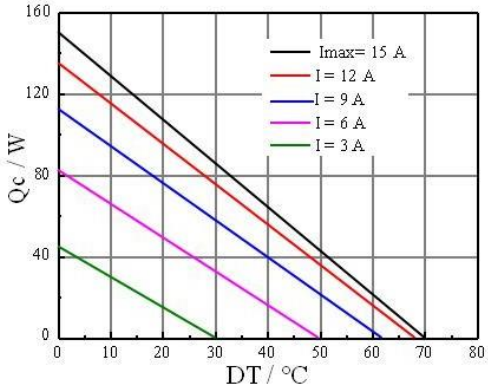
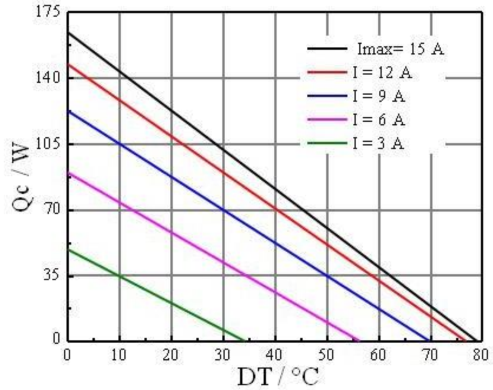
SI.NO	DIMENSIONS	MEASURE (in mm)
1	Length	50
2	Thickness	4
3	Breadth	50

GRAPHICALY ANALYSED CHARACTERISTICS PROVIDED IN MANUFACTURER DATA SHEET:-

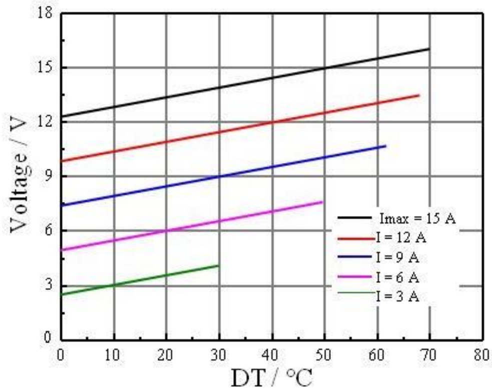
Performance Curves at Th=27 ℃

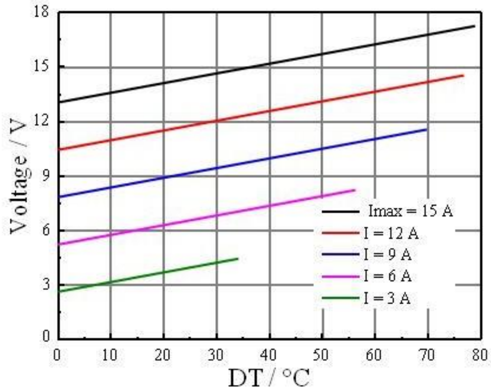
Performance Curves at Th=50 ℃



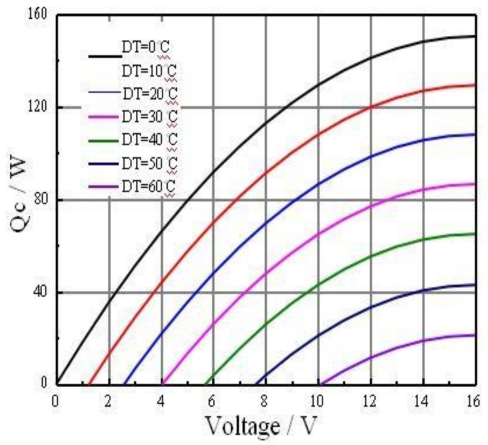


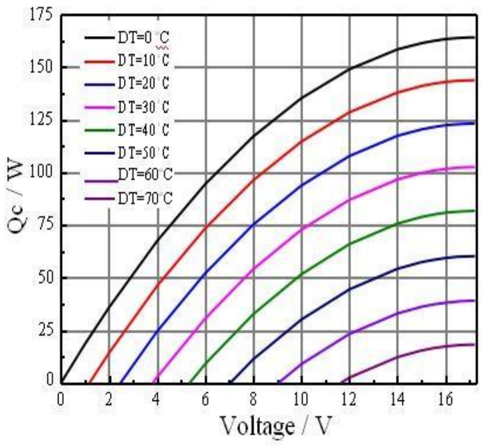
Standard Performance Graph Qc= f(DT)





Standard Performance Graph V= f(DT)





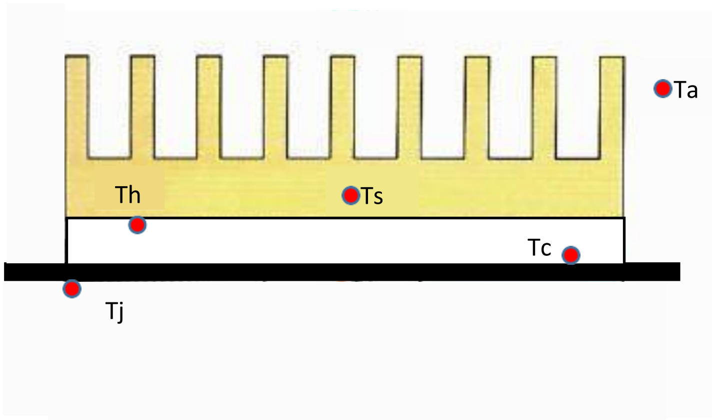
Thus the module TEC1-12175 has better heat transfer characteristics with efficient temperature difference about 69 degree Celsius. The power consumption of this module is also moderate while comparing to the other modules available in the market.

HEAT SINK:-

The heat sink is used for excavating the heat transferred by the Thermo-electric modules.

THERMAL CIRCUIT:-

The heat dissipating and absorbing components are modeled into thermal circuit with respect to their thermal parameters as given below.



(HEAT SINK

Where as :-

Q: total power or rate of heat dissipation in W. Tj: maximum temperature of the device in °C. Tc: cold side temperature in °C. T_h: hot side temperature in °C. Ts: sink temperature in °C.
Ta: ambient air temperature in °C.

Using temperatures and the rate of heat dissipation, a quantitative measure of heat transfer efficiency across two locations of a thermal component can be expressed in terms of thermal resistance R, defined as

R = T/Q k/w

Thus for calculating the total power rate of heat dissipation the temperature considerations are performed with respect to the estimated data of temperature values in real time systems as given below,

TEMPERATURE LEVELS AS PER REAL TIME DATA:-

The maximum temperature of switch in power converter **Tj = 120º C**

The average temperature difference can be obtained by

TEC-Module , TEC1-12715 = 75º C (approximated to below rated value)

From this data we can calculate the maximum cold side temperature that can be obtained from TEC-Module by using the formula,

TCold = Tj-DTmax

= 120º C - 75º C

T_{Cold} = 45º C

Therefore , **Temperature at cold side of TEC-Module =45º C**

Temperature at hot side of TEC-Module:-(without heat sink)

Thot = DTmax+TCold

= **75º C + 45º C**

T_{hot} = 120º C

Similarly the hot side temperature is appeared as the Skin temperature of the heat sink thus ,

T_s = 120º C

Ambient temperature level around power converter **T_a= 50º C**

Assuming that , heat loss on the converter heat sink be 0.5% of its input power

Then for a 1MW power converter the heat loss will be 5KW. Thus the heat loss in the converter be 5KW.

Q=5KW

The Thermal conductivity of aluminium = 250 w/m.k The thermal resistance of aluminium = 0.004 w Thus, **T= QR s**

=5000×0.004

T=20s

Time required for cooling for aluminium case of unit volume is 20s.

Similarly the power absorbed by the heat sink in 20ms is given by,

Q_{obs}= R/T KW

The thermal resistance of heat sink is given in data sheet is R=0.8K/W Thus,

Q=0.8/20

Q_{obs}=40 watts

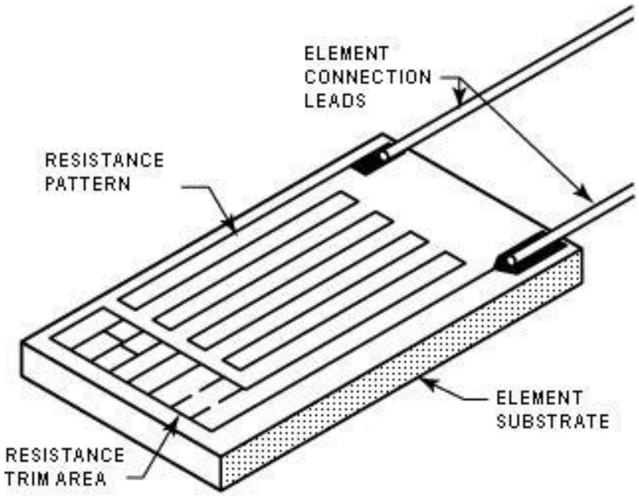
TEMPERATURE SENSOR AND ITS CONTROL:-

Temperature detection is the foundation for all advanced forms of temperature control and compensation. The temperature detection circuit itself monitors ambient temperature. It can then notify the system either of the actual temperature or, if the detection circuit is more intelligent, when a temperature control event occurs. When a specific high temperature threshold is exceeded, preventative action can be taken by the system to lower the temperature.

RESISTANCE TEMPERATURE DETECTOR (RTD):-

An RTD, also known as a resistance thermometer, measures temperature by correlating the resistance of the RTD element with temperature. An RTD consists of a film or, for greater accuracy, a wire wrapped around a ceramic or glass core. The most accurate RTD’s are made using platinum but lower-cost RTD’s can be made from nickel or copper.

However, nickle and copper are not as stable or repeatable. Platinum RTD’s offer a fairly linear output that is highly accurate (0.1 to 1 °C) across
-200 to 600 °C. While providing the greatest accuracy, RTD’s also tend to be the most expensive of temperature sensors.



(The structure of RTD)

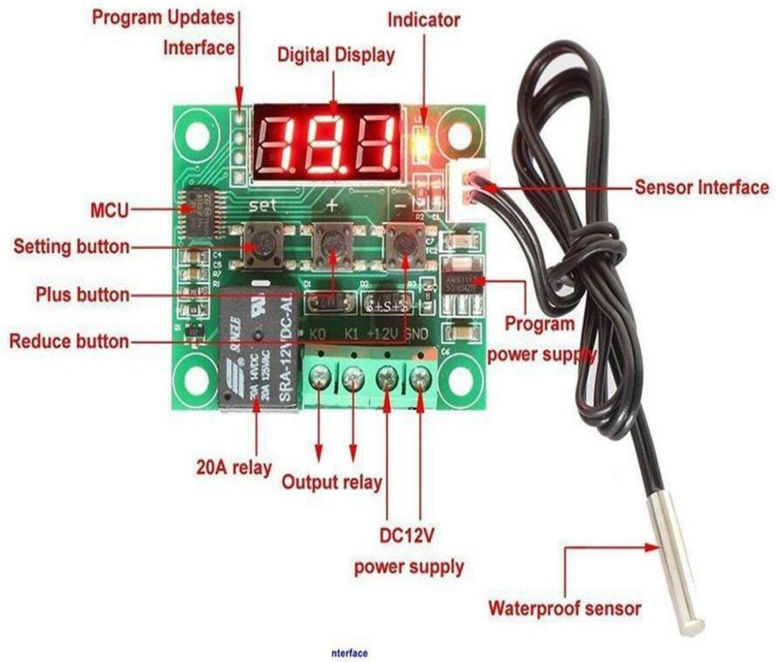
Thus for linearity, cost efficient and accuracy the copper film RTD is used.

TEMPERATURE CONTROLLER W1209:-

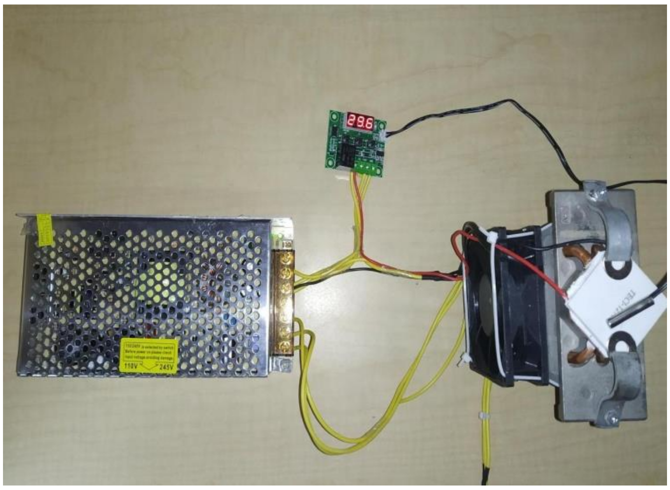
W1209 thermostat module has a temperature sensor, keys, LED display, relay and requires DC 12V power supply. Thermostats are devices that sense the temperature of a system so that the temperature is maintained at the desired set point or near to it. RTD temperature sensor allows the module to intelligently control varied electrical devices based on the temperature.

NTC thermistor has a negative temperature coefficient, which means the resistance decreases with increasing temperature.

W1209 has an inbuilt embedded micro-controller, thus not much programming knowledge is required. The module consists of three switches to configure the various parameters including ON and OFF trigger temperatures. The relay can operate at voltages up to a maximum of 240V AC at 5A or 14V DC at 10A to power on. The temperature is displayed in degree centigrade and with the help of 7-segment display and the relay, the state is displayed with the help of the LED present on the W1209 module.



Schematic circuit of

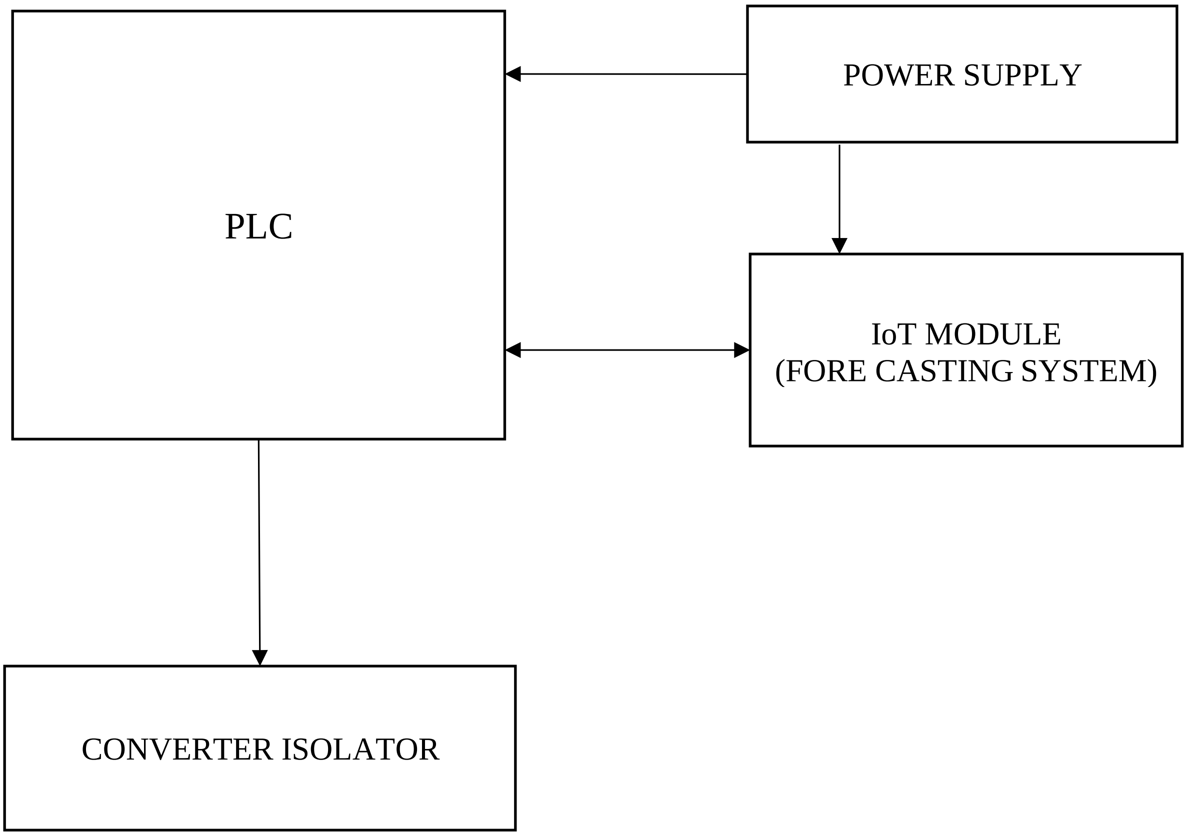


PLC-(PROGRAMMABLE LOGIC CONTROLLER)

The PLC is used as control and processing unit for the whole temperature monitoring system. The composite modules are connected to the PLC through relay units. Thus the triggering of relay in controller module is also given for PLC as input and also The temperature sensor output is given to the PLC. Thus the main use of PLC is to interface the system with IoT. It is used while large number of modules are used.

FORECASTING SYSTEM:-

The forecasting system receives the data form PLC and process it for forecasting to the monitoring user by using IoT communication systems. It also receives the manual control commands from users and sends to the PLC for intermediate processing.



ORGANIZED WORKING OF THE OVERALL SYSTEM:-

The temperature sensor monitors the temperature over the portioned surface of heat dissipating bodies and gives live data to PLC. The PLC process the data from the temperature sensor and give it to forecasting system . When the temperature controller detects the continuous rise in temperature level, It powers the Peltier module and cooling fan.Thus the cooling system is activated till the temperature of the body is kept for safer level. The forecasting systems transmit the live temperature data to the user through IoT interfaces .Through this system user can completely monitors the heat dissipation and control even though the automatic system is employed. Any malfunction of the system is detected the PLC sends the emergency alert to the user as well as electrically isolates the system and generator if required.

CUSTOMLY DESIGNED COMPOSED MODULE

PRACTICALLY ANALYZED DATA USING EXPERIMENTAL MODULE:-

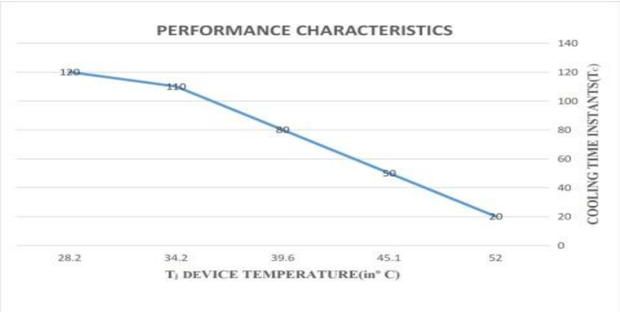
- Material taken = Aluminium plate
- Dimensions = 100mm×100mm×1mm
- Thermal conductivity = 205 (W/m K)
- Switching device = 20n60 (smps power mosfet)
- Maximum temperature = 120º **C**
- Device optimum efficient temperature = 45º **C TABULATION:-**

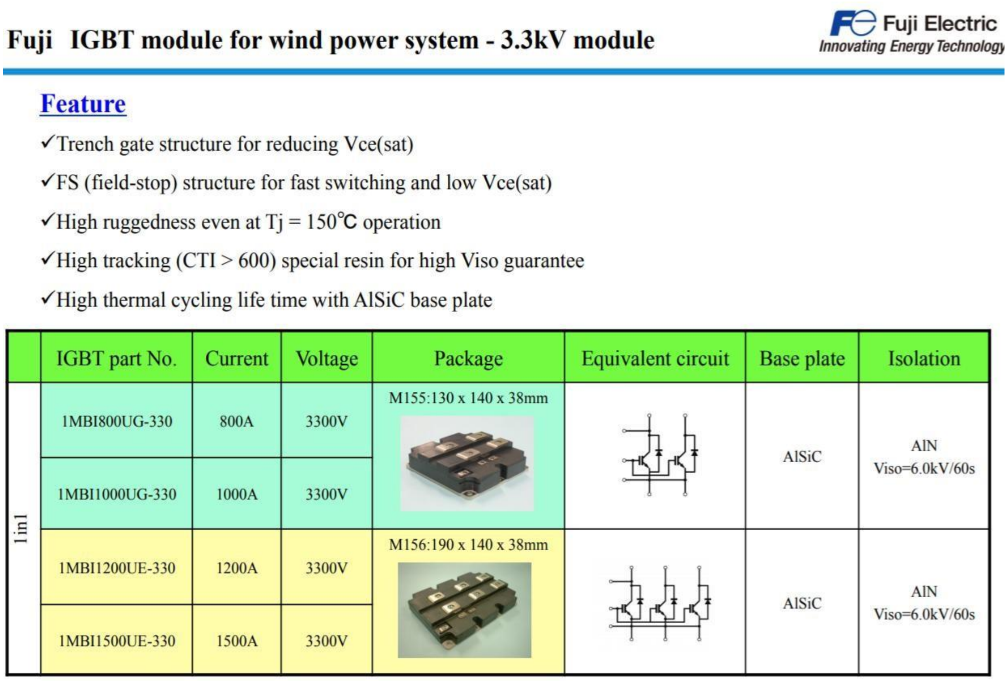
SI.NO	APPLIED VOLTAGE (inV)	$I_{PELTIER}$ (in A)	T_C - COLD SIDE TEMPERATURE (inº C)	T_C - HOT SIDE TEMPERATURE (inº C)	T_j - DEVICE TEMPERETURE (inº C)	COOLING TIME INSTANT (T_c)
1	12.2	2	50	28	52	20s
2	12.2	3.2	43.5	37.5	45.1	50s
3	12.2	3.8	38.6	48.9	39.6	80s
4	12.2	4.9	32.4	62.8	34.2	110
5	12.2	5.5	27.1	79.3	28.2	120s

GRAPHICAL REPRESENTATION:-

ANALYTICAL DESIGN FOR IGBT COOLING:-

LET US CONSIDER FUJI IGBT MODULE:-





FOR ANALYSIS PURPOSE CONSIDER IGBT-1MBI1000UG-330:-

Max power capacity = 3300×1000

P_{max} = 3.3 MW

Maximum operating Temperature. = 150º C

NUMBER OF COPOSED MODULE REQUIRED:-

With respect to practically analyzed data, one module can efficiently cool the object with dimension 100mm×100mm×1mm. Thus for efficient cooling
Two modules are used for cooling the above mentioned IGBT.

ADVANTAGES OF TEC-MODULE COOLING METHODOLOGY:-

- Thermo-electric generators do not require any fluids for fuel or cooling, making them non-orientation dependent allowing for use in various applications.
- This method is completely free from maintenance.
- The solid state design is easily mounted with existing production methods and allows for operation in severe environments.
- Thermo-electric generators have no moving parts which produces a more reliable device that does not require maintenance for long periods.
- The durability and environmental stability have made Thermo-electric a favorite for eco-friendly one among other applications.
- One of the key advantages of Thermo-electric generators outside of such specialized applications is that they can potentially be integrated into existing technologies.
- The weight of the system is extremely low while compared to other systems.
- The efficiency of the system is 40% higher than other systems.
- The temperature can be monitored lively from any where because of using IoT.
- It can be easily mounted with any kind of systems without changing a lot in its structure.

(Note:-The implementation of PLC and IoT based Forecasting system is not implemented in experimental kit due to insufficiency of time.)

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