Chapter 3

3 Load Controlling Techniques

Different load controlling techniques are adopted in modern load banks, such as,

1. Linearly Switching
2. Binary Switching
3. Linearly Switching with Binary Tailing
4. Linearly Switching with PWM Tailing

3.1 Linearly Switching

In the linearly switching load controlling technique, the total load is achieved by switching equal power elements (load resistances) in an incremental manner. Hence, the resolution of the load bank is the rating of one power element. The main drawback of this method is the inability to achieve a power levels within its resolution limits. To improve the resolution, more power elements with smaller ratings have to be used incurring cost and space.

3.2 Binary Switching

In binary switching technique, the power elements are rated in the values of two's power such as1, 2, 4, 8, 16, 32, 64, etc. The desired load is achieved by switching the combination of the binary components. This technique is normally used in load banks with lower power ratings, since the higher ratings require switching on of load elements with higher ratings demanding high capacity switching devices, contactors, etc.

3.3 Linearly Switching with Binary Tailing

The load is achieved by a combination of binary elements and linearly switching elements. When load banks with higher power ratings are considered, this technique is used to increase the resolution and to limit the capacity of switching devices, contactors, etc.

3.4 Linearly Switching with PWM Tailing

In linearly switching with PWM tailing technique, a power controller with a Power Electronic Switching Device (PESD) is used to linearly switch the power elements to achieve the desired load and to compensate the variation of the load due to the variation of ambient conditions such as temperature there by.

The applicability of the three above discussed load controlling techniques depends on the robustness of the cooling design as well as the required accuracy.

3.5 Application of Power Controllers in Automatic Load Controlling

The resistance of the load bank varies with the temperature and multitude of other transient parameters. The de-rating curve of a particular resistor, gives its resistance value at a given temperature. However, the temperature stated in the de-rating curve is the surface temperature of the resistor which is same as the surrounding ambient temperature. This temperature is dependent on the air flow provided by the cooling system of the load bank which is subjected to transient variations due to disturbances in the air flow pattern.

The question of controlling the load bank at a specified load is primarily dependent on the cooling provided as well as the development of a controller to negotiate with transient variations. The purpose of the cooling system is to maintain the surface temperature of the resistors below the de-rating temperature by an appropriately designed cooling mechanism to transport heat energy to ambient. Any deviation of the values of resistors has to be compensated by a power controller.

The power controller has to be designed using power electronic switching devices with an appropriate feedback controller system, in order to maintain the resistance of the load bank at a constant value, despite its marginal transient variations. For this, the controller should provide fast responses with free of oscillations to resistor variations. The switching device should be capable of handling the maximum power of the switching power element of the power controller. The switching frequency is selected such that it is at least ten times higher than the frequency of temperature variation and also to minimize the switching losses.

3.5.1 Operation of the Automatic Load Controller

Figure 3.1 shows the circuit diagram of a load bank with an automatic power controller (PWM controller).

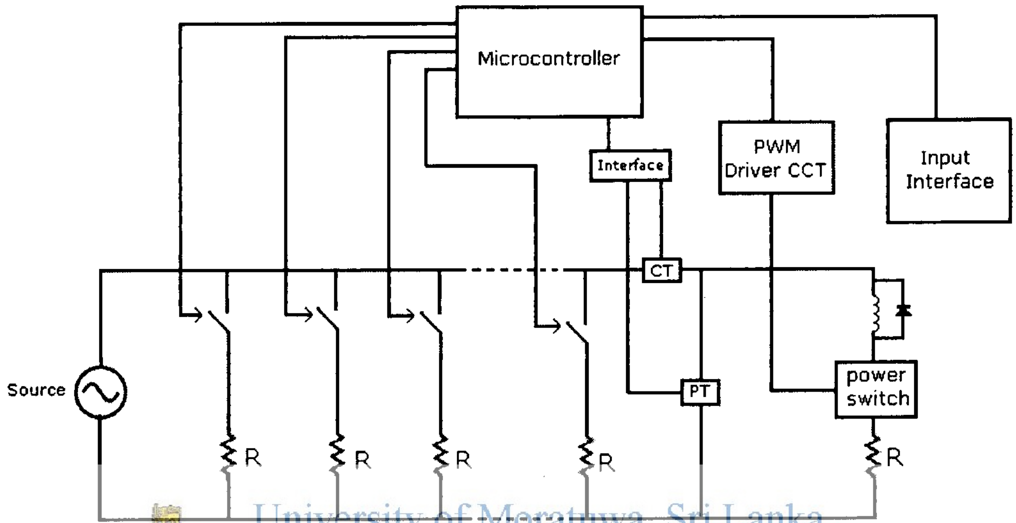

Figure 3.1 - Load bank with an Automatic Power Controller

Once, the desired power level is set, the power controller switch on the respective resistor combination and any variations of the desired load due to the temperature variations is compensated using PWM controlled power element. Instead of the power electronic devices the banks without the PWM switching can deploy any other actuator switch.

The operation can be described using an example. The desired power output is taken as 20kW and the PWM controlled maximum power output is taken as 2kW. The rating of linear switching power elements is also taken as 2kW (R accounts for 2kW). Once the power value is set as 20kW in the Input Interface, the controller switches on ten numbers of 2kW power elements to cater the 20kW output. Any reduction in the load due to temperature variations is supplied by the PWM controlled power element. When the reduction of load due to temperature variation is higher than 2kW, which is beyond the PWM adjustable power, the controller switches on the next resistor element. Still, the total power is below 20kW, hence the balance has to be supplied by the PWM controlled element. If the temperature variation accounts for making required PWM controlled power to go beyond 2kW again, the controller has to switch on the next power element. Similar controlling is happening in the reversed direction when the required power from the PWM controlled element reaches zero.

3.6 Automatic Load Controlling Model

A model was developed using MATLAB Simulink to simulate automatic load controlling technique. It shows how the effect of temperature on resistance is compensated using the controller action. The controlled action can be discussed using the developed model shown in *Figure 3.2*.

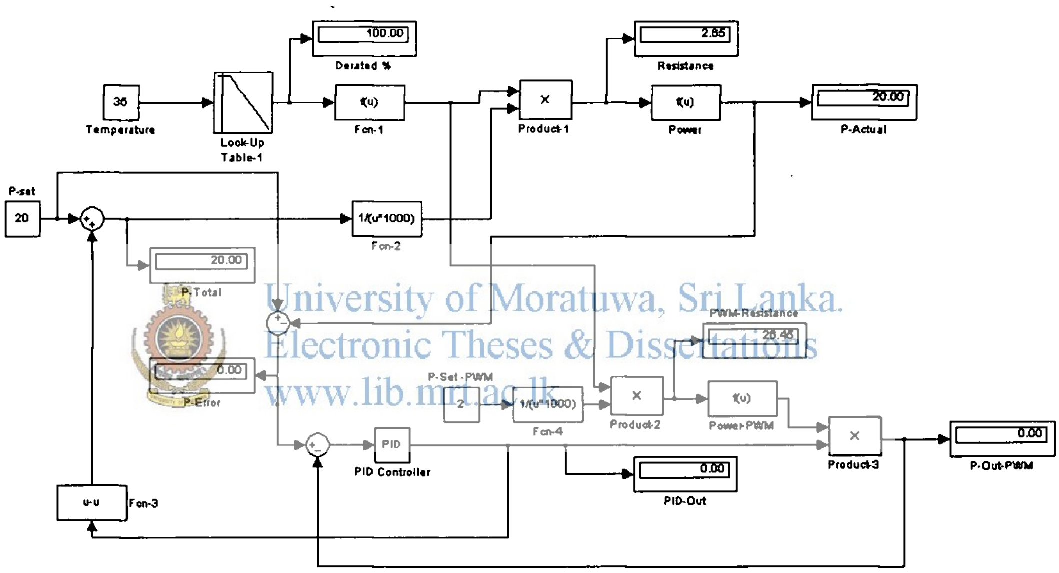

Figure 3.2 – Model for Automatic Load Controlling

The model has three inputs,

- Temperature : ambient temperature around the resistors, taken as 35^0C
- P-set : value of the desired load, set by the user, taken as 20kW
- P-PWM : PWM controlled power value of the controller, set by the user, taken as 2kW

When the required power value of the load bank is set in the user interface, the controller sets the P-set value accordingly by connecting the correct resistor combination. However, the corresponding power value will reduce due to derating of resistors with the increase in temperature. To account for this, the temperature around the connected resistors is taken as an input to the Look-Up Table-1 (*Figure 3.3*) which contains the temperature derating curve of the power resistors. The output is the corresponding derated percentage load. The product of functions *Fcn-1* and *Fcn-2* gives the total derated resistance.

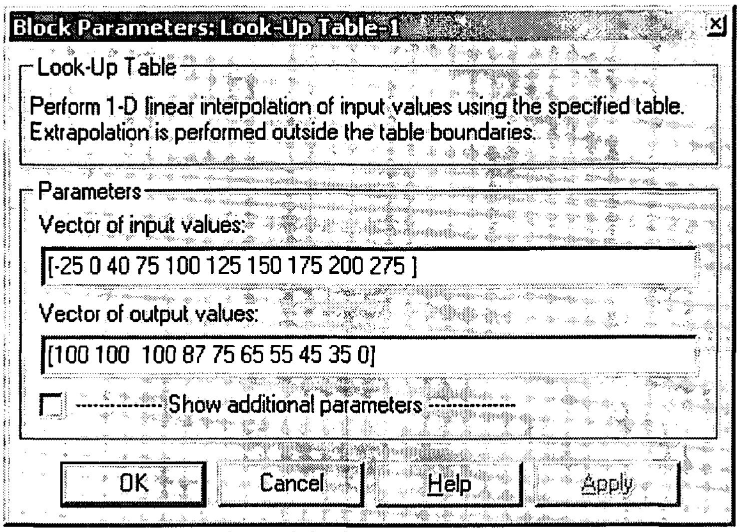

Figure 3.3 – Look-Up Table-1

The corrected power is calculated considering the derated resistance value, using the function *Power*, and compared with the P-set value. The error is fed to the PID controller.

The derated resistance of the PWM controlled power element at the given temperature is also calculated using the derated curve in Look-Up Table-1 as discussed above and the product of function *Fcn-1* and *Fcn-4*. The corrected power is calculated using the function *Power PWM* and multiplied by the PID output to get the controlled PWM power output. The result is fed back to the PID input to get the error signal. In this way, the PID controller compensates the derated power of the load bank with the PWM controlled power element.

The model shown in *Figure 3.2*, uses the temperature around the resistor as 35^0C hence no derating is present. Due to this reason, the PWM controlled power element is not required.

Figure 3.4 shows the case where the temperature is 60^0C. In here, the PWM controlled power is used to maintain the power set value.

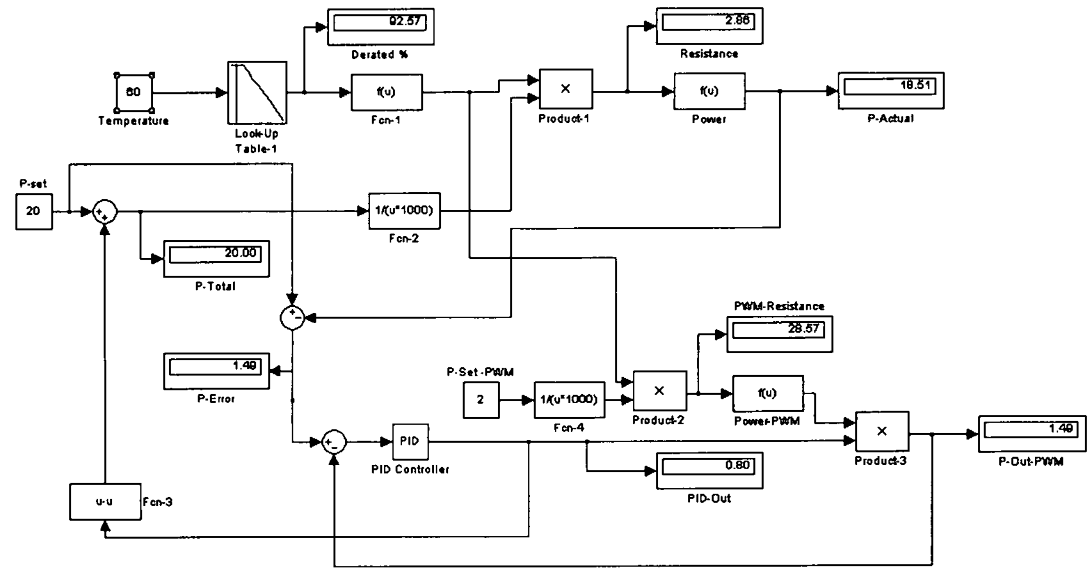

Figure 3.4– Automatic Load Controlling with PWM Controlled Power Element

The function *Fcn-3* monitors the PID output. If the PID output reaches to a level where the PWM controlled power out put requirement is more than 2kW, then it connects an additional power element to get 2kW load to maintain the set power. The system again calculates the corrected power due to temperature increase and the balance, which is now below 2kW, is supplied by the PWM controlled element. The process continues by adding 2kW power elements with the increase in temperature and removing 2kW power elements with the decrease in temperature. The addition of a power element is shown in *Figure 3.5*.

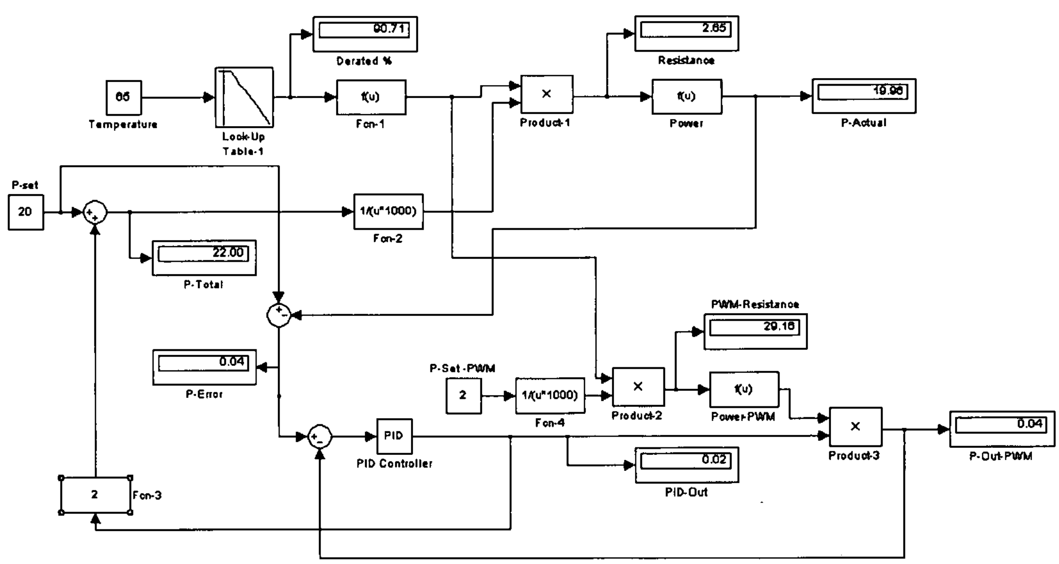

Figure 3.5 – Automatic Load Controlling with Additional Switching ON of Power Elements

The functions used in the model discussed are as follows,

- Fcn-1 = 230 ^ 2 / (0.01 * u)
- Fcn-2 =1 / (u * 1000)
- Fcn-3 = User defined control logic for the resistor switching.
- Fcn-4 =1/(u * 1000)
- Power =(230 ^ 2 / u) / 1000
- Power PWM =(230 ^ 2 / u) / 1000

where, u is the input.