DEVELOPMENT OF MODEL PREDICTIVE CONTROL FOR HVAC SYSTEMS IN COMMERCIAL BUILDINGS.

18MT880 PROJECT

Submitted in partial fulfillment for the requirement of B.E. degree in Mechatronics Engineering of Anna University

Submitted by

Balaji B

18F007

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Guided by

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Professor

Department of Mechatronics Engineering

THIAGARAJAR COLLEGE OF ENGINEERING

(A Govt. Aided, Autonomous Institution, Affiliated to Anna University)

MADURAI – 15

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BONAFIDE CERTIFICATE

Certified that this is a bonafide record of the 18TMT880 Project & Viva Voce done by **BALAJI B (reg. 18F007), NIKHILESH BABU TRM (reg. 18F027)** of Eighth Semester B.E. Mechatronics Engineering during the year 2018 – 2022.

Signature of the Guide   Signature of H.O.D.MCT

Station: Madurai   Date:

Submitted for Viva-Voce examination held at Thiagarajar College of Engineering, Madurai – 625 015, on ________________.

INTERNAL EXAMINER   EXTERNAL EXAMINER   H.O.D.MCT

CERTIFICATE

This is to certify that the **18MT880** Project Report entitled **DEVELOPMENT OF MODEL PREDICTIVE CONTROL FOR HVAC SYSTEMS IN COMMERCIAL BUILDINGS**, being submitted by **BALAJI B (reg. 18F007), NIKHILESH BABU TRM (reg. 18F027)** in partial fulfillment for the requirement of **Bachelor of Engineering Degree in Mechatronics Engineering**, is a record of bonafide work. The results embodied in this report have not been submitted to any other university or institute for the award of any degree or diploma.

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Abbreviations

Abbreviations	**Meaning**
HVAC	Heating Ventilation and Air conditioning
PID	Proportional Integral Derivative
MPC	Model Predictive Control
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
FODT	First Order Delay Time

ABSTRACT

HVAC, which stands for Heating Ventilation and Air Conditioning is important in providing thermal comfort to the occupant while maintaining indoor air quality such as Purity, Humidity Temperature. The main challenge and motive of HVAC is to control the air quality of enclosed space. In this work, A MPC, which stands for Model Predictive Control Algorithm is used. Model predictive control has numerous advantages that are suitable for temperature control. An internal plant model to generate control inputs based on the feedback from the sensors is used to control the HVAC system to maintain the air quality of a enclosed space with a volume of $1800m^3$ (6m X 4.5m X 4.5m). The developed system is also compared with existing controllers namely PID.The settling time, which is the time taken for the system to reach its steady state, is low in MPC technique(0.54 seconds). Whereas the PID has a settling time of 3.08 seconds. The Overshoot, Which is expressed in percentage of the final value of the system, is the signal that exceeds the target value in MPC is 3% which is comparatively lower than that of PID, which is at 7.8%.

CHAPTER - 1

INTRODUCTION

1.1. Motivation and Objective

HVAC is not only limited to commercial structures such as homes, Skyscrapers, Textile showrooms , Schools and Institutions, but also helps in maintaining industrial environment qualities such as humidity and temperature. The concept of HVAC is applied in the Cold room , Freezer room, Blast freezer , and Ripening chamber for maintaining food quality. The Objective of the project is to develop a MPC based controller for HVAC systems.There are many control techniques used in the field of control systems. HVAC systems such as Air-conditioners, Nowadays use PID based, Relay based and thermostat(Bang–bang control) based controllers.

PID controllers are most commonly used as conventional thermostats in today's commercial buildings' Heating, Ventilation, and Air-Conditioning (HVAC) systems. It enables occupants to adjust to desired temperatures through the use of preset temperatures. Essentially, the thermostat detects the current temperature and only reacts if there is a difference between the current and set temperatures by sending additional alerts to the occupants.

On the contrary, the MPC controller provides remarkable benefits when used in HVAC systems, with the key advantage of being able to deal with constraints. The MPC controller has one significant advantage over the PID controller in that it can manage a variety of constraints. Furthermore, the MPC controller necessitates the use of a process model, whereas the PID controller does not.

Furthermore, according to one study comparing the MPC and PID controllers, the MPC controller performs better in the Heating, Ventilation, and Air-Conditioning (HVAC) simulation test. Under steady-state conditions, the MPC takes less time to reach the set point, and the offsets are smaller than with the PID controller. Overall, the performance of the MPC controller is superior to that of the PID controller.

These controllers are not suitable for dynamic and multivariable control problems such as HVAC, in which the air quality depends on numerous parameters such as Occupancy, Climate conditions, Wall thickness, Humidity, Temperature etc…,. The Model Predictive Control method works efficiently with multivariable and dynamic systems. The motivation behind the project is that the Model Predictive Control technique works more efficiently than PID, which will in turn decrease the cost and increase the lifetime of the equipment while providing a better Air comfort for occupants.

1.2. Outline of the Thesis

Chapter-1 gives a brief introduction about the HVAC systems and Model predictive techniques. Chapter-2 provides the literature survey of the research papers done on the HVAC, MPC and PID topics by various authors. The summary of the literature survey is discussed at the end of chapter-2. Chapter-3 defines the motivation and objectives stated for the project. Chapter-4 gives an overview about the existing control techniques used in HVAC fields, such as PID and On-Off control technique. The disadvantages of the existing works are mentioned at the end of chapter-4. This is then compared with the current work. The advantages of the developed systems are also provided. The Chapter-5 discusses the design and simulation of MPC for HVAC in Commercial buildings. The design considerations and simulation results are provided. The chapter-6 provides the observations and findings of the developed solution. The developed solution is also compared with the PID controller and the results are tabulated. The scope for future works is also mentioned.

1.3. Fundamentals of HVAC

1.3.1 Heating

Heaters are devices which provide warmth to the building or environment.Heating can be done using several methods, such as Convection, Conduction and Radiation heat transfer. Heat pumps are used to provide warmth to the environment by extracting heat from various sources such as environment, exhaust or from ground, thus providing better efficiency than other methods like boiler and furnace. The generated heat is distributed through pipes with the help of a pump.

1.3.2 Ventilation

Ventilation, which is the most important factor for maintaining indoor air quality, is the process of replacing or changing the indoor air with outdoor air, which is often done intentionally to maintain humidity, remove moisture, bacteria, carbon-dioxide and to change the temperature of the building.

Ventilation mainly helps in maintaining the indoor oxygen quality. Ventilation can be categorized to two types,

1. Forced Ventilation
2. Passive Or Natural Ventilation

Forced ventilation is achieved with the help of AHU, Which stands for Air Handling Unit, to maintain the indoor air quality by mixing the outdoor air with indoor air to achieve the desired humidity, moisture level and odor.

Passive or Natural ventilation is the process in which indoor air quality is maintained without the help of fans or AHU. ASHRAE defined Natural ventilation as the process of maintaining the indoor air quality with the help of circulation through windows, doors and grilles.

1.3.3. Air Conditioning

An Air conditioning system or A/C is a system which provides cooling and maintains humidity of the overall building. Air conditioned buildings have sealed/closed windows to maintain the indoor air temperature and humidity at a desired level.

The outdoor air which is drawn with the help of a vent, is mixed with indoor air with the help of AHU and Mixing chamber. The percentage of outdoor air is controlled by adjusting the opening of the vent.

Air conditioning and removal of heat is provided through the Refrigeration system. The heat transfer medium is most of the modern system is through chemicals which are referred as Refrigerants. The refrigerant is used in a refrigeration system which is driven by a pump.

1.3.4 Vapor-compression Refrigeration cycle

Vapor-compression refrigeration system,also known as VCRS is widely used in air conditioning of buildings and automobiles. There are two heat exchangers in the system, namely

1. Condenser
2. Evaporator

The condenser, being the hot end, releases heat to the outside environment and the other end being the evaporator is colder and accepts heat from the indoor environment.

The cycle starts with the refrigerant flowing through the compressor at low pressure. Super heated gas leaves the outlet of the compressor with high pressure and temperature. The superheated gas travels through the condenser and loses heat to surroundings and condenses completely. The high pressure liquid passes through the Expansion/ Throttle valve, where a sudden drop in pressure reduces the temperature. Air is blown over the evaporator, which inturn cools the indoor air.

The efficiency of the refrigerator is given by $COP_R = \frac{Desired\ Cooling\ effect}{Work\ Done}$, where the desired cooling effect is the amount of heat needed to be removed from the system and work done is the amount of work done by the compressor to achieve the cooling effect.For a carnot refrigerator the above formula can be expressed in terms of Temperatures as follows

$$COP_{R,Carnot} = \frac{T_L}{T_H - T_L}$$

Where TL is lower temperature limit and TH is Higher temperature limit.

CHAPTER - 2

LITERATURE SURVEY

2.1. LITERATURE REVIEW:

Muharrem Imal [1] developed a Proportional integral derivative based controller for HVAC systems which improves energy efficiency by 40% than the actual systems. The paper also includes design of Human Machine Interface for supervisory control of HVAC systems. Energy optimization is achieved by controlling AC drives of the Ventilation and Exhaust fans.

Servet Soyguder et al [2] developed an HVAC system with damper gap rates controlled by a PID controller. The required temperature for the interested indoor volume was used to control one of the dampers. To improve the system's performance, PID parameters were optimized using a Fuzzy Modeling Approach. ANFIS-based solutions can provide faster and simpler solutions, the authors say

Nikola Hure et al [3] proposes a model predictive controller for a building chiller that uses various information to minimize cooling costs in an electricity market with volatile electrical energy prices. The obtained controller reduces cooling costs while adhering to the imposed comfort constraints. To validate the performance of the proposed controller in the simulation scenario, a case study HVAC system model is used.

Serale et al [4] proposed a common dictionary and taxonomy that serves as a foundation for all engineering disciplines involved in building design and control.Model Predictive Control (MPC) for energy management in buildings is becoming increasingly viable. MPC has found success in building thermal regulation by fully utilizing the potential of building mass. It has also been successfully applied to active energy storage systems and the optimal management of renewable energy sources. Because of its ability to consider constraints, predict disturbances, and multiple conflicting objectives, MPC opens up several opportunities for improving energy efficiency in the operation of HVAC systems.

Chetan D et al[5] using, Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software, an analysis study was conducted for a First Order Delay Time (FODT) model controlled by Proportional Integral Derivative (PID) and Model Predictive Control (MPC) controllers. This paper demonstrates how to use MPC practically and provides an overview of the MPC implementation in LabVIEW. The obtained simulation results are compared between the PID and MPC controllers. The Performance Comparison shows a good correlation between the PID and MPC controllers.

J.B. Rawlings[6] developed a reasonably accessible and self-contained tutorial exposition on model predictive control (MPC). It is aimed at readers with control expertise, particularly practitioners, who wish to broaden their perspective in the MPC area of control technology. We introduce the concepts, provide a framework in which the critical issues can be expressed and analyzed, and point out how MPC allows practitioners to address the trade-offs that must be considered in implementing a control technology.

Dana Copet et al[7] proposed a concise guideline as to how, when, where, and what to apply when it comes to choosing the most suitable control strategy as a function of multi-parameter objective optimization. Both proportional-integral-derivative (PID) and model predictive control (MPC) control are addressed in this context.

Mohd Hezri Marzaki et al[8] proposed the comparative performance of Model Predictive Controller (MPC) and PID controller in controlling temperature on Small Scale Industry Steam Distillation Pilot Plant (SSISD). The performances were evaluated based on three criteria such as time constant, settling time and percentage overshoot. The simulation and real-time results revealed that the MPC controller was capable of meeting desired transient response specially on providing fast settling time and minimum overshoot compared with PID. The paper contains the simulation and real time studies of those controllers that applied at Small Scale Industry Steam Distillation Pilot Plant (SSISD).

Yeng chai shoh et al[9] presented a practical method to optimize the in-building section of centralized Heating, Ventilation and Air-conditioning (HVAC) systems which consist of indoor air loops and chilled water loops. First, through component characteristic analysis, mathematical models associated with cooling loads and energy consumption for heat exchangers and energy consuming devices are established.

Anthony D Kelmen[10] presented a field experiment results from the implementation of a model predictive controller which optimizes the operation of a variable volume, dual-duct, multi-zone HVAC unit serving an existing mid-size commercial building. This full-scale proof-of-concept study was used to estimate the benefits of implementing advanced building control technologies during a retrofit. The control approach uses dynamic estimates and predictions of zone loads and temperatures, outdoor weather conditions, and HVAC system models to minimize energy consumption while meeting equipment and thermal comfort constraints.

Jixia Han et al[11] developed a control algorithm that is based on the performance of a model and online application optimization. The feedback control strategy has been extensively researched over the last 40 years. However, due to the rapid development of the economy, the requirements for online optimization and constrained performance have increased, and the current model predictive control theory can no longer meet the demand. This paper first briefly describes the current state of model prediction, industrial development, and application areas, then analyses the current limitations of theory and technology, and finally proposes the importance of studying predictive control of large-scale systems, fast dynamic systems, and nonlinear systems for the development of model predictions.

Yu Geng Xi et al[12] proposed Model predictive control (MPC) theory and technology have advanced rapidly over the last 30 years. However, in the face of increasing demands for constrained optimization control as a result of the rapid development of the economy and society, current MPC theory and technology face significant challenges. The evolution of MPC theory and industrial applications is briefly reviewed in this paper, and the limitations of current MPC theory and technology are discussed. The importance of strengthening MPC research in order to improve its effectiveness, scientificity, and usability is emphasized. The work summarizes recent developments and new trends in the theoretical study and applications of MPC, and emphasizes the importance of MPC research for large scale systems and fast dynamic systems.

2.2. LITERATURE SUMMARY

Based on the extensive literature survey, the following observations are made,

A. PID control technique works better than existing control techniques used and it improves the energy efficiency of HVAC systems.
B. PID controllers do not work well with non-linear models more efficiently than Model predictive control technique.
C. Model predictive control technique not only improves efficiency but also improves the life of the HVAC system.

CHAPTER - 3

PROBLEM IDENTIFICATION

3.1. PROBLEM STATEMENT:

In the literature survey section, it is observed that the MPC works better than PID with non-linear models. Model predictive control also provides features such as constraints and future predictions which cannot be achieved with PID. MPC improves the efficiency and the life of the HVAC systems.

Many non-linear variables exist in HVAC systems, including temperature, pressure, humidity, and relative humidity (RH). As a result, for HVAC systems, MPC is preferable to PID. A PID controller does not have constraints on the input and output values generated by the controller, whereas an MPC controller can.

3.2. OBJECTIVES:

From the literature survey, the below objectives are formulated,

- To develop a MPC based controller for HVAC systems in commercial buildings.
- To develop the HVAC model for the commercial buildings in Matlab.
- To simulate the designed Model predictive controller for HVAC in Matlab simulink.
- To compare the performance of PID and MPC controller in Matlab simulink.

CHAPTER -4

METHODOLOGY

4.1. Existing Methodology

4.1.1. Overview:

There are many control techniques available in the field of control systems. Among these, the existing air conditioning systems use simple PID or On - Off which is also known as Bang Bang controllers. The On - Off control technique is used in thermostat based control of HVAC and Refrigeration systems.

4.1.2. Proportional Integral Derivative controller

A Proportional Integral Derivative or PID is a widely used industrial control system that works with feedback in a control loop. A PID Controller continuously calculates the error value of the feedback by comparing it with the setpoint values and applies the control signals based on the proportional(Kp), Integral (Ki) and Derivative(KD) values. The first practical PID controller was implemented for controlling steering angle of Ships in the early 1920's. After that PID controller was introduced in pneumatic and electronic industries for automation. Due to its optimal performance nowadays, It is implemented in many industrial automation areas.

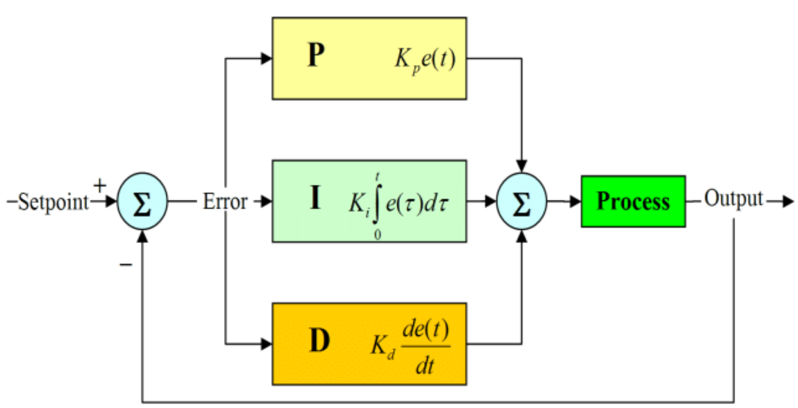


Fig 1 PID block diagram

The Term P stands for proportionality and it is directly proportional to current error value of the system. For example, if the value of error is positive and large, then the control input will be larger according to the Kp value. If there is no error, then the no control input will be generated.

Term I calculates the I term by accounting for historical values of the error and integrating them across time. For example, if there is a residual error after the application of proportional control, the integral term seeks to eliminate the residual error by adding a control effect due to the historic cumulative value of the error. When the error is eliminated, the integral term will cease to grow.

Term D is the best estimate of the error's future trend based on its current rate of change. It is sometimes referred to as "anticipatory control" because it seeks to reduce the impact of the error by exerting a control influence generated by the rate of error change. The greater the rate of change, the greater the controlling or dampening effect.

4.1.3. Limitation of PID

While PID controllers are applicable to many control problems and frequently perform satisfactorily without any improvements or only coarse tuning, they can perform poorly in some applications and do not provide optimal control in general.

The fundamental problem with PID control is that it is a feedback control system with constant parameters and no direct knowledge of the process, so overall performance is reactive and a compromise.

While PID control is the best controller in an observer without a model of the process, better performance can be obtained by explicitly modeling the actor of the process without using an observer.

When the PID loop gains must be reduced so that the control system does not overshoot, oscillate, or hunt around the control setpoint value, PID controllers alone can provide poor performance.

They also struggle in the presence of non-linearities, may trade-off regulation versus response time, do not respond to changing process behavior (for example, the process changes after it has warmed up), and have lag in responding to large disturbances.

4.1.4. On Off control technique

On Off control technique, which is technically referred as Bang Bang control technique or two step control is a common method that is implemented in thermostats. These are very easy to implement but it reduces the life of the equipment as it changes from On to Off state abruptly.

These are often implemented in systems that have only two states, i.e. the system can be only fully On or fully Off. This control technique is used by most of the simple thermostats available in markets.

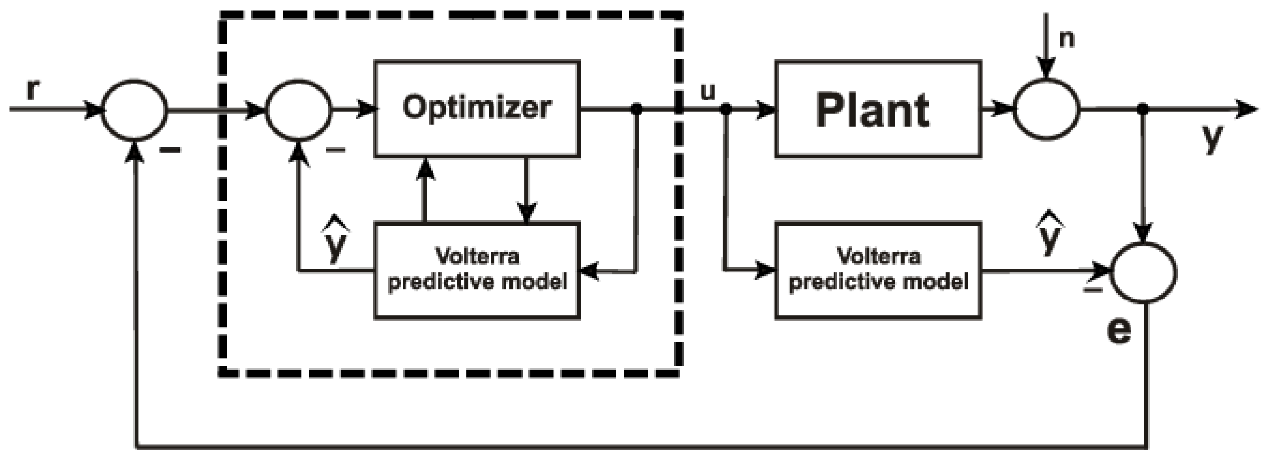
4.1.5. Limitation of On Off control

The On Off control technique provides very poor control over the state of systems and often the control inputs are imprecise which results in low accuracy of the system. On the other hand, the On Off control technique leads to premature wearout and damage of the equipment.

4.2. PROPOSED METHODOLOGY

4.2.1 Overview

Model predictive control is an advanced technique for process control which is used to control a process while satisfying certain constraints. Process control is a discipline that uses industrial control systems to achieve a high level of consistency, safety and accuracy that cannot be done with the sole help of humans. The model predictive control works using the dynamic model of the system. The models are designed using system identification, which is a process of deriving mathematical models of dynamic systems from data using statistical methods. MPC has been used by Oil refineries and chemical plants since the 1980s. Nowadays, Due to advancement in computing technologies, it has been used in power systems and power electronics.



4.2.2. Advantages of proposed methodology

Model predictive control is an advanced process control technique that is better suited for Multi Input Multi Output systems(MIMO) than PID control techniques.

The Main advantage of the MPC technique is that it allows one to optimize the current state of the system, while considering the future states of the system. The MPC has the ability to estimate the future events and act accordingly.

In MPC we can have constraints for the input and output of the controller, which cannot be achieved using PID.

Model Predictive control is an online optimization technique, which makes it resilient to dynamic changes in feedback.

CHAPTER -5

Design and simulation of MPC

5.1. Overview

MPC technique is a multivariable control algorithm that uses the model of the system to control and make predictions of the system's future behavior. The MPC uses a kalman filter to predict future states of the system.

The Kalman filter, which is also known as linear quadratic estimation(LQE) produces estimates of unknown variables using the measurements observed over time.

The MPC controller, then selects the optimal control input from the estimates to drive the state of the system to reference value.

There are three main parameters to be considered while designing the MPC controller.

1. Sample time
2. Prediction Horizon
3. Control Horizon

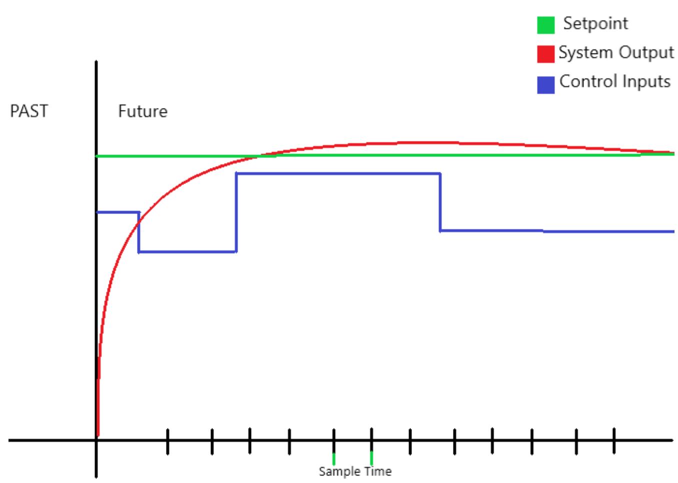


Fig 2

Sample time is defined as the rate at which the controller reacts to the system changes. The Sample time value is crucial while designing the controller, because a small value for sample time may cause the controller to react too fast to system changes, which in turn requires a high computational performance. On the other hand, If the value for sample time is set to a large value, then the controller will not be able to react to disturbances faster and this may lead to poor performance of the controller.

Prediction Horizon defines how far the controller looks into the future. If the value is too small, Then the controller makes control action based on the short time period, which makes the controller less reactive to future disturbances. If the value is too large, then it makes the controller slow and makes the controller vulnerable to present system disturbances.

Control horizon defines the control actions that are required to reach the plant output in the given sample time. The values from the prediction horizon are fed to the optimizer to get the control horizon values. Hence, Fewer the control horizon value, Fewer the computations made by the controller.

5.2. Design of Model predictive controller for HVAC systems

HVAC systems have many non-linear variables such as temperature, pressure, humidity and Relative Humidity(RH). So, it is ideal to choose MPC instead of PID for HVAC systems. A PID controller does not have constraints over input and output value generated by the controller, whereas MPC can enforce constraints on input and output values.

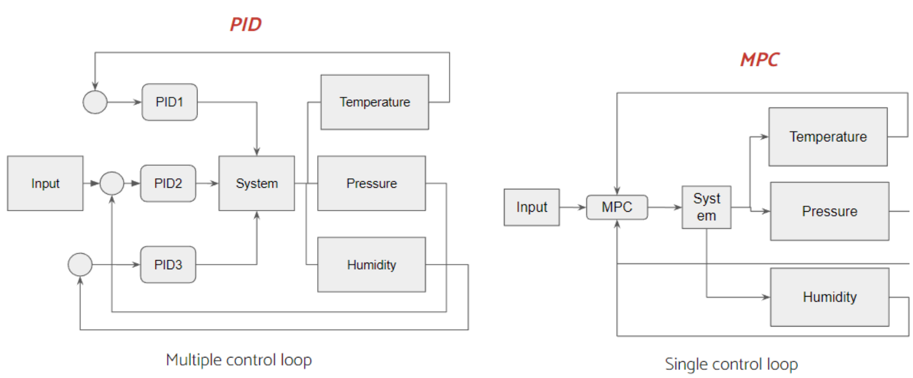


Fig 3

PID control systems require multiple control loops for controlling HVAC systems, meanwhile MPC can work with a single control loop. The above figure clearly shows that the PID requires a separate controller for each feedback which can be simplified to a single control loop with MPC technique.

5.3. Modeling of Refrigeration cycle

5.3.1 Compressor

The compressor in HVAC is used to compress the refrigerant, which in turn increases its overall temperature. A compressor can be modeled in Matlab with the help of a Controlled mass flow rate source. This component generated a time varying mass flow rate in a two phase fluid network.

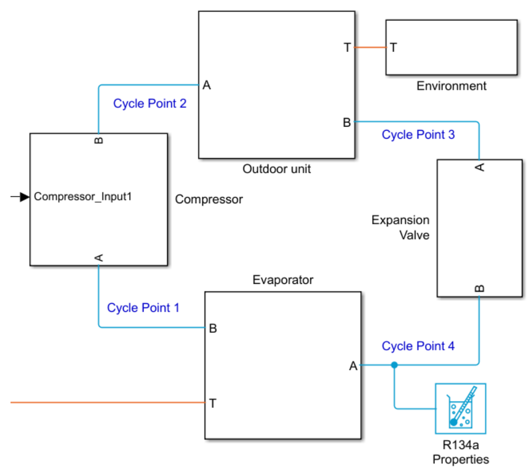


Fig 4

5.3.2 Condenser

The condenser is the outdoor part of the HVAC system, which will reject the heat to the environment, helping in cooling of the refrigerant. Condenser coil is made using Copper tubings with aluminum fins, which is mounted with a fan to cool the pipes. These can be modeled with the help of the Pipe component in Matlab, which is used to simulate the dynamics of two phase liquid inside a pipe.

5.3.3 Expansion Valve

The Expansion valve, which is placed between condenser and evaporator controls the flow of refrigerant from condenser into evaporator. The expansion valve restricts the flow rate of the refrigerant. This can be modeled in Matlab using Variable Local Restriction (2P). Variable flow restriction is used to model pressure drop due to variable flow restriction in a two phase fluid system.

5.3.4 Evaporator

The Evaporator is made using copper pipes that help in removing heat from the system which needs to be cooled. The modeling of the compressor is similar to that of the condenser which is modeled using Pipe.

5.4 Identification of Thermal loads

Thermal loads are sources of heat that are present inside the indoor environment such as Devices, Occupants, Radiation from roof and basement etc..,. The heat sources can be categorized into,

1. Sensible heat
2. Latent heat

Sensible heat comprises the heat sources that can be felt or measured. Examples of sensible heat are heat rejected by devices, Occupant load, Radiation from sun, etc..,.

Latent heat is the result of change in moisture content of the room. This can be from moisture from the atmosphere, sweating from the occupants or devices inside the room(Moisture due to boiling water or cooking).

Heat transfer occurs through convection heat transfer, where the medium of heat transfer is air. The convection heat transfer from the evaporator can be modeled using Convective Heat Transfer.

The indoor environment is separated from the environment using the wall, which can be considered as an insulator of heat. This can be modeled using Conductive heat transfer and convective heat transfer in series. The thermal conductivity of the wall is set to 0.8 W/mK which is taken from Design & Specification considerations understanding 'k' values. The thickness of the wall is set to 230mm.

The environment temperature is simulated in matlab with the help of Temperature source and the temperature is set to 33℃, which is the average temperature at Madurai, Tamilnadu - India, which can be found in the weather forecast.

The Air, Roof, window and door of the building are assumed to have thermal mass, which is the ability of material to absorb and store heat. The thermal mass can be simulated using Thermal mass component in Matlab .

The Building is assumed to have a door, a window and roof, for which the thermal load is modeled using convective heat transfer in matlab and thermal mass.

The heat gains of the occupants are modeled using the Heat flow rate source in Matlab with the number of occupants set to five.

5.5 Relative Humidity(RH) and Dewpoint temperature

Relative humidity or RH refers to the ratio of actual moisture content present to the amount of moisture content if the air was saturated. Relative humidity is expressed in percentage. This is the amount of moisture that can be retained without condensation.

Dew Point temperature denotes the temperature at which the moisture content of the atmosphere will condense.

Dew point	Comfortness zone
<50 °F (<10 °C)	a bit dry for some
50 - 60 °F (10 - 16 °C)	dry and comfortable(Selected RH)
60 - 65 °F (16 - 18 °C)	getting sticky
65 - 70 °F (18 - 21 °C)	unpleasant, lots of moisture in the air
>70 °F (>21 °C)	uncomfortable, oppressive, even dangerous above 75 °F

The above table denotes the comfortness level for humans at a given dew point temperature. The relationship between RH and Dew Point can be expressed using the Magnus-Tetens formula, Where $\lambda = 243.04°C$ and $\beta = 17.625$ ℃ are magnus coefficients.

$$D_p = \frac{\lambda * (ln(\frac{RH}{100}) + \frac{\beta T}{\lambda + T})}{\beta - (ln(\frac{RH}{100}) + \frac{\beta T}{\lambda + T})}$$

CHAPTER - 6

RESULTS AND DISCUSSION

6.1. Overview

The MPC controller is designed in Matlab simulink with the help of Model Predictive Control Toolbox, which helps in designing Model predictive controllers for linear and non linear control systems. The toolbox provides apps and components that can be used in designing controllers. It also provides review of the controller design and the performance can be tested by running the simulation.

6.2 Design and tuning of controller

The controller is tuned using the Model predictive control toolbox. The temperature and humidity feedback signals are fed to the controller using a multiplexer.

The toolbox linearizes the HVAC system developed and tests the controller sensitivity using step response.

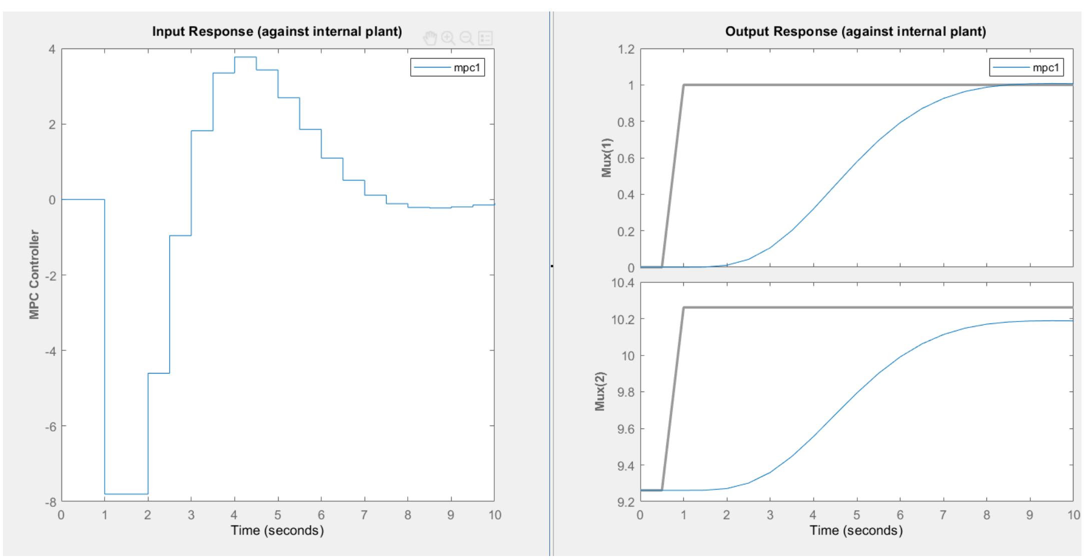
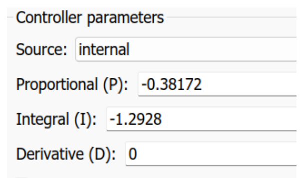


Fig 5

The above image shows the step response of a plant model of Humidity and Temperature controlled using an MPC controller.

6.3. Comparison of PID and MPC controller

The PID controller is tuned using the PID auto tuner in Matlab simulink. The Kp, Ki and KD are computed as follows,



The below images show the result of MPC and PID response of the system with Step input.

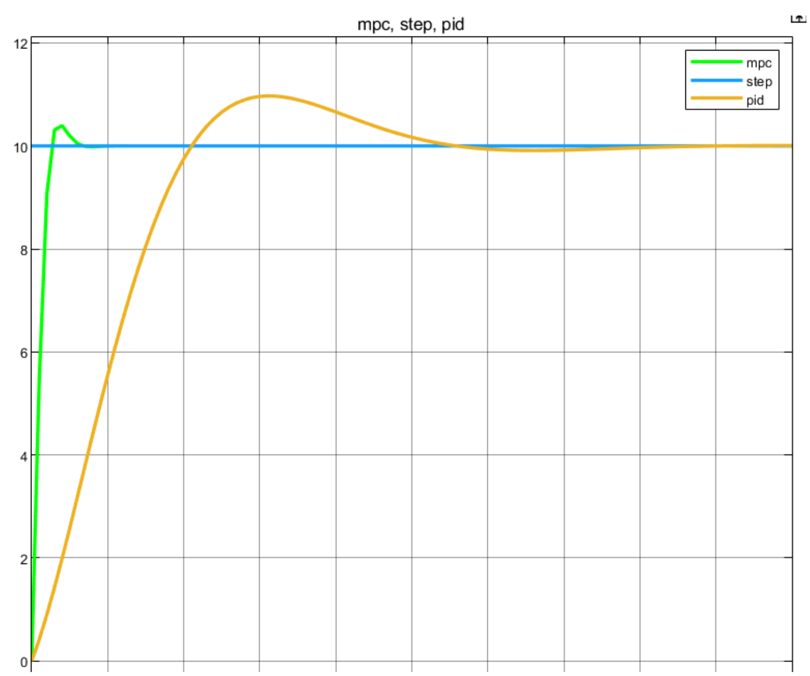


Fig 6

In control systems engineering, two controllers are compared based on the following parameters

1. Rise Time
2. Settling time
3. Overshoot

Rise time is defined as the time taken for the system to reach from x% to y% of the final value. It is usually 10% to 90% of the final value.

Settling time is the time taken for the system to reach its steady state. The steady state range is between 2% to 5% of the final value.

Overshoot, Which is expressed in percentage of the final value of the system, is the signal that exceeds the target value.

The Rise time, Settling time, Overshoot and Peak of the controllers are compared with help of Matlab step info.

```
pid_data =

  struct with fields:

        RiseTime: 0.8680
    SettlingTime: 3.0804
     SettlingMin: 9.2406
     SettlingMax: 10.7829
       Overshoot: 7.8289
      Undershoot: 0
            Peak: 10.7829
        PeakTime: 1.8000
```

```
mpc_data =

  struct with fields:

        RiseTime: 0.2245
    SettlingTime: 0.5445
     SettlingMin: 9.8923
     SettlingMax: 10.3112
       Overshoot: 3.1118
      Undershoot: 0
            Peak: 10.3112
        PeakTime: 0.4000
```

Fig 7

It can be clearly observed that the Rise time, settling time and Overshoot of the MPC controller is low when compared to PID controllers.

CHAPTER - 7

CONCLUSION

7.1. CONCLUSION

The primary challenge and goal of HVAC is to regulate the air quality in enclosed spaces. A MPC, which stands for Model Predictive Control Algorithm, is used in the proposed work. Model predictive control offers numerous advantages for temperature control. An internal plant model is used to generate control inputs based on sensor feedback to control the HVAC system in order to maintain the air quality of an enclosed space with a volume of $1800m^3$ (6m X 4.5m X 4.5m). The proposed system is also evaluated in comparison to existing controllers such as PID. The MPC controller is created in Matlab Simulink using the Model Predictive Control Toolbox, which aids in the creation of model predictive controllers for linear and nonlinear control systems.

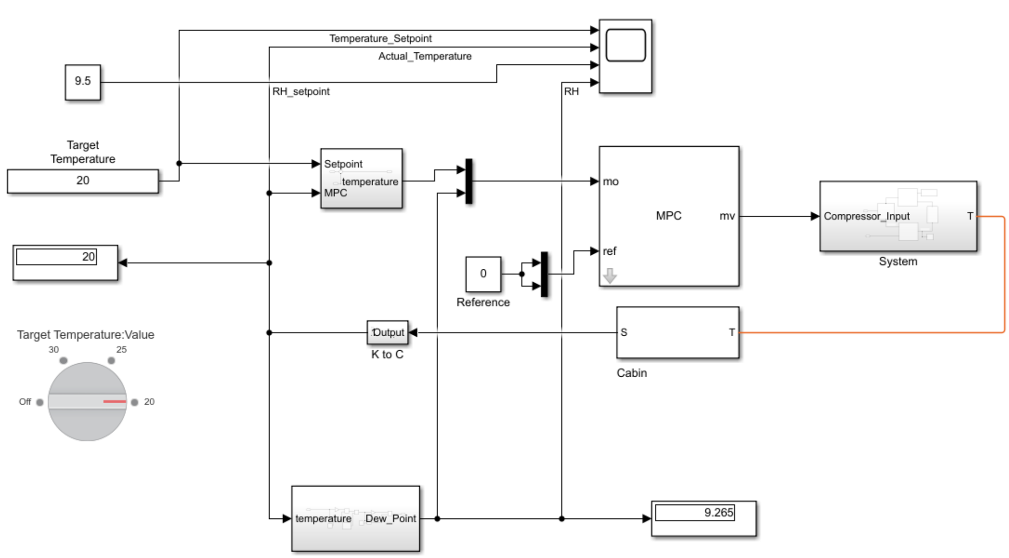


Fig 8

The above image is the completed Matlab simulink model of HVAC system controlled using Model predictive controller.

The simulations of the HVAC systems with Model Predictive Control technique proves that it is a good alternative for existing control techniques such as Proportional Integral Derivative and On-Off control technique.

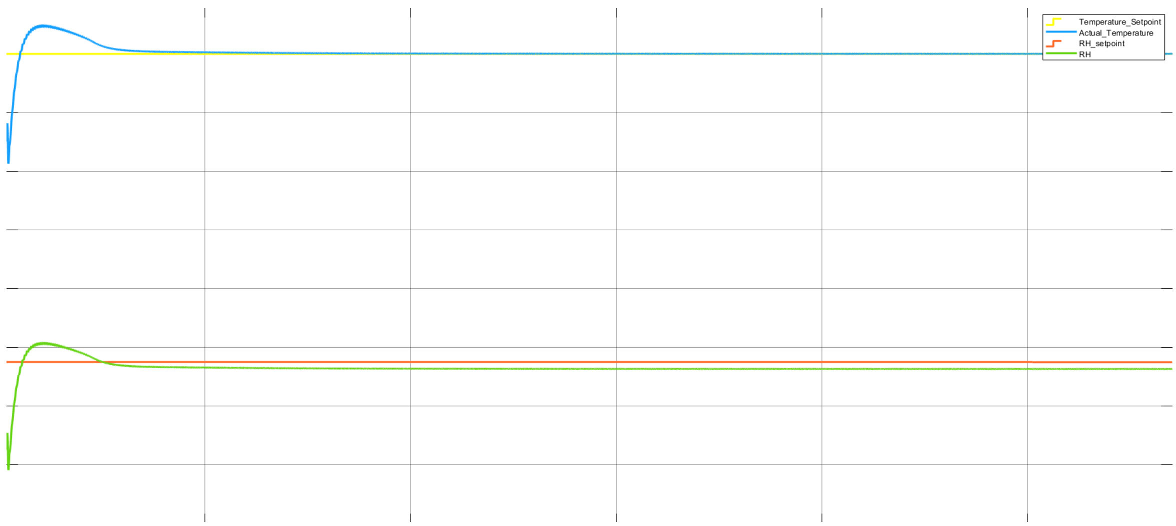


Fig 9

The above graph is plotted between Setpoints and actual values of Temperature and Dew Point temperature which is used to control Relative Humidity.The Model predictive controller works with a settling time of 0.54 seconds which is much smaller than settling time of PID(3.08 seconds).

7.1.1. SCOPE FOR FUTURE WORK

Due to scarce resources of the HVAC systems, Data dynamic system modeling is not implemented. As a result, the designed controller can be only implemented to buildings that fit the design parameters. This can be improved by dynamic modeling of systems using system identification methods with data. As a future work, the controller designed in matlab can be exported as deployable C code and can be tested in a real environment. There are other new emerging control techniques such as Deep neural networks that can be used to optimize the control of HVAC systems.

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