Evolutionary Algorithms based Controller design for cold storage system

Mohamed Hussain K, Maheswari L, Revathi S, Sivakumaran N

Department of Instrumentation and Control Engineering, National Institute of Technology, Tiruchirappalli, 620015

Abstract. Implementing optimization for control variables for electrical based storage process results in increase of the energy efficiency. Optimization can implemented for the control variable of the process that are key aspects to the increase of energy efficiency. Thus for the cold storage process controlling of evaporator inlet temperature and heat load has done. This in turn provides effectiveness to temperature of chamber and power consumption. Mathematical Modelling of cold storage is a multi-input multi-output (MIMO) system and it has done by converting the differential equations to the first order plus dead time (FOPDT) system and summating the systems accordingly. This resulted in obtaining the curves of the evaporator inlet temperature (Te), chamber temperature (Tc) and power consumption (Pc) in open loop. Optimization techniques such as Simulated Annealing (SA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) have used for optimizing the PID Controller which in turn controlling the system. The comparison studies of time domain specifications for these controllers has done and the suitable controller for the process has obtained.

Keywords: Cold Storage, Simulated Annealing (SA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) and Genetic Algorithm (GA), Proportional Integral Derivative (PID) Controller.

1 Introduction

Every day, metric tons of temperature based sensitive products have produced and generated [8]. The Fruits and vegetables (F&V) will deteriorate when operating conditions such as temperature, humidity and life changes [3]. The advantage of cold storage is mentioned in the paper by author Wei Dong et. el. [7]. The storage of fruits and vegetables (F&V) have done by cold storage to increase the shell life and slows the deterioration rate [2]. The cost of cooling by cold storage device (CSD) has reduced by implementing modern power consumption techniques [1]. Renewable energy is the alternative for the cooling and cold storage when grid supply is done or to reduce the consumption of grid. Combined energy mechanism helps to increase the efficiency than a system dependent on a single source [5]. Multi-energy system refers converts one form of energy to other in terms of hubs and connections to one or more energy sources [6]. Speed control of compressor plays a major role in efficiency increment of the energy system. The thermal load varies when the speed of compressor varies which in turn varies the operating temperature. Therefore, the input variables are compressor frequency and heat load or thermal load in the cold storage unit. By means of maintain the optimal temperature, automatic continuous time control of the cold storage unit can obtain [4]. These techniques ensure that optimum temperature can obtain very rapidly so that efficiency increases [9]. The temperature control of storage system tends to increase the power consumption and equipment preservation and it also maintains the quality of the products inside the chamber [10]. The techniques are focussing on optimization or minimization of error. The remaining portions of the paper deals with the modelling of cold storage system with effect to frequency of compressor and heat load variation of the compressor. Obtaining transfer function for every input output relation. Here, in this problem there are two inputs and three outputs therefore the system model has six transfer functions. Each transfer function is an effect of the particular input to a particular output. The output is a sum of product of transfer function to the two inputs. The process is six first order plus dead time transfer function process. The control of evaporator inlet temperature Te, chamber temperature Tc and power consumption P have done by optimization techniques such as Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) for proportional integral derivative (PID) controller. The comparison of time domain specifications will discussed. The suitable controller for the system will obtained.

2 Experimental Setup

The experimental cold storage system consists of two cold rooms' cold room one and two respectively each of inner dimension 1.2 metres in length, 0.6 metre in breath and 1.88 metres height respectively. Each has the storage capacity of 150 kg. The storing items are Fruits and Vegetables. Each fruits and vegetables (F&V) have unique storage temperature, humidity and shell life. For example, mango has maintained in temperature of 8-13^{0}C, 20% humidity and shell life of 3-6 weeks.

Fig.1. Cold Storage System

3 Modelling

The cold storage system described here is a continuous time invariant system. It deals with the dynamic behaviour of variables such as temperature and power. The input variables of the system are Frequency of the Compressor Fr(s) and heat load He(s). The output variables that are to be controlled, they are: Evaporator Inlet Temperature Te(s), Chamber Temperature Tc(s) and Power Consumption P(s). For every combination of two inputs and three outputs, there is a First Order plus Dead Time (FOPDT) transfer function has obtained. The change of frequency Fr(s) function corresponds to the transfer functions $G_{Fr\text{-}Te}(s)$, $G_{Fr\text{-}Tc}(s)$ and $G_{Fr\text{-}P}(s)$. The following are the possible transfer functions. These obtained by making the specific input as constant and others as zero.

$$G_{Fr-Te}(s) = \frac{T_e(s)}{F_r(s)} \quad (1)$$

$$G_{Fr-Tc}(s) = \frac{T_c(s)}{F_r(s)} \quad (2)$$

$$G_{Fr-P}(s) = \frac{P(s)}{F_r(s)} \quad (3)$$

The change of heat load He(s) function corresponds to the transfer functions $G_{He\text{-}Te}(s)$, $G_{He\text{-}Tc}(s)$ and $G_{He\text{-}P}(s)$.

$$G_{He-Te}(s) = \frac{T_e(s)}{H_e(s)} \quad (4)$$

$$G_{He-Tc}(s) = \frac{T_c(s)}{H_e(s)} \quad (5)$$

$$G_{He-P}(s) = \frac{P(s)}{H_e(s)} \quad (6)$$

The outputs Te, Tc and P are the sum of the effect of input variables as shown below.

$$T_e(s) = F_r(s)G_{Fr-Te}(s) + H_e(s)G_{He-Te}(s) \quad (7)$$

$$T_c(s) = F_r(s)G_{Fr-Tc}(s) + H_e(s)G_{He-Tc}(s) \quad (8)$$

$$P(s) = F_r(s)G_{Fr-P}(s) + H_e(s)G_{He-Te}(s) \quad (9)$$

The open loop model for the cold storage system is as follows:

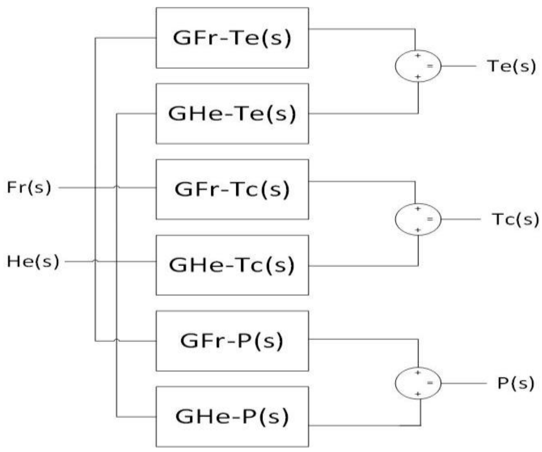


Fig.2. Open Loop Model Diagram of Cold Storage system

The Open loop response of Evaporator inlet temperature (Te) and Chamber temperature (Tc) in degree Celcius will be as follows:

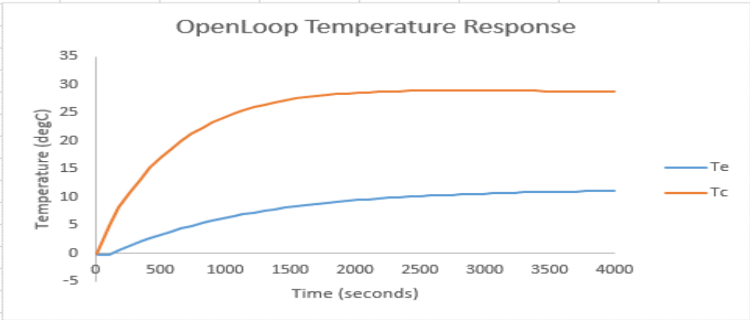


Fig.3. Open Loop Response of Temperatures Te and Tc (in degree Celsius)

The Open loop response of Power Consumption in watts (P) will be as follows:

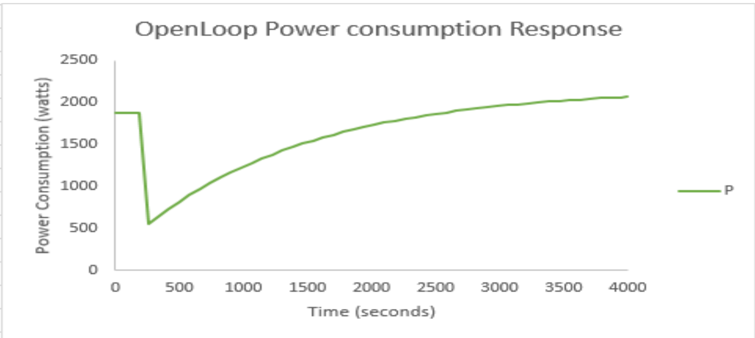
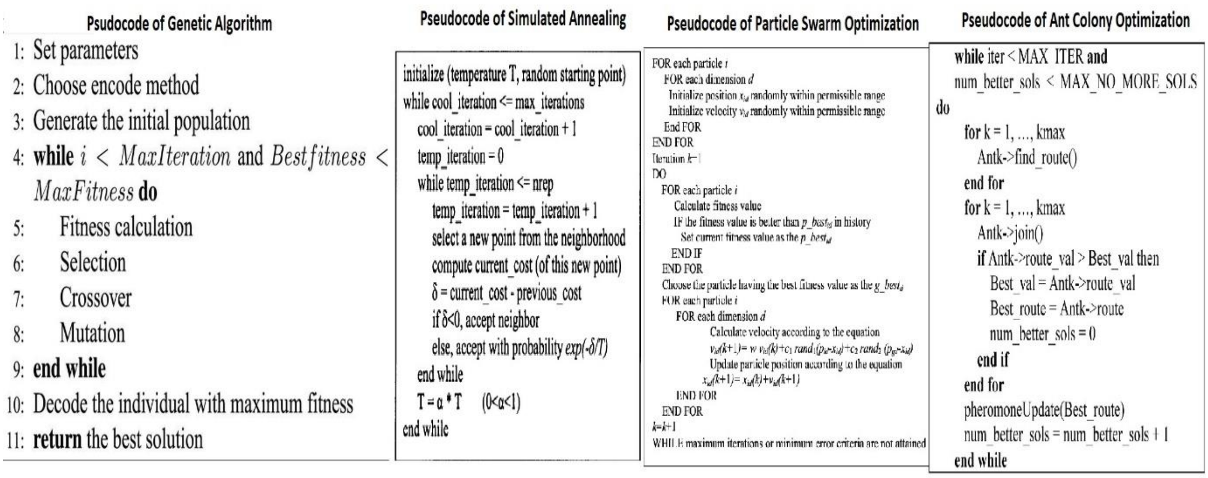


Fig.4. Open Loop Response of Power Consumption P (in watts)

4 Tuning of PID Controller

The open loop responses obtained in the previous section have to be controlled. For that purpose, temperature and power consumption oriented optimal control techniques such as Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) have carried out for tuning the Proportional Integral Derivative (PID) Controller. The curves of the variables Evaporator inlet temperature Te, Chamber temperature TC and Power consumption P have plotted based on the above tuning techniques and the result has shown in the results and comparison section.



Psudocode of Genetic Algorithm

```
Set parameters
Choose encode method
Generate the initial population
while i < MaxIteration and Bestfitness < MaxFitness do
    Fitness calculation
    Selection
    Crossover
    Mutation
end while
Decode the individual with maximum fitness
return the best solution
```

Pseudocode of Simulated Annealing

```
initialize (temperature T, random starting point)
while cool_iteration <= max_iterations
  cool_iteration = cool_iteration + 1
  temp_iteration = 0
  while temp_iteration <= nrep
    temp_iteration = temp_iteration + 1
    select a new point from the neighborhood
    compute current_cost (of this new point)
    δ = current_cost - previous_cost
    if δ<0, accept neighbor
    else, accept with probability exp(-δ/T)
  end while
  T = α * T    (0<α<1)
end while
```

Pseudocode of Particle Swarm Optimization

```
FOR each particle i
  FOR each dimension d
    Initialize position x_id randomly within permissible range
    Initialize velocity v_id randomly within permissible range
  End FOR
END FOR
Iteration k=1
DO
  FOR each particle i
    Calculate fitness value
    IF the fitness value is better than p_best_id in history
      Set current fitness value as the p_best_id
    END IF
  END FOR
  Choose the particle having the best fitness value as the g_best_d
  FOR each particle i
    FOR each dimension d
        Calculate velocity according to the equation
        v_id(k+1)= w v_id(k)+c1 rand1(p_id-x_id)+c2 rand2 (p_gd-x_id)
        Update particle position according to the equation
      x_id(k+1)= x_id(k)+v_id(k+1)
    END FOR
  END FOR
k=k+1
WHILE maximum iterations or minimum error criteria are not attained
```

Pseudocode of Ant Colony Optimization

```
while iter < MAX_ITER and
num_better_sols < MAX_NO_MORE_SOLS
do
  for k = 1, ..., kmax
    Antk->find_route()
  end for
  for k = 1, ..., kmax
    Antk->join()
    if Antk->route_val > Best_val then
      Best_val = Antk->route_val
      Best_route = Antk->route
      num_better_sols = 0
    end if
  end for
  pheromoneUpdate(Best_route)
  num_better_sols = num_better_sols + 1
end while
```

Fig.5. Pseudocodes of Tuning Algorithms

5 Results and Comparison

The comparison of time domain specifications shows that Genetic Algorithm based PID controller is suitable for the given cold storage system with less settling time. The optimal techniques based PID controller discussed in the previous sections will implemented and the output response for the outputs Te, Tc and P are as follows:

5.1. Output Response for Evaporator Inlet Temperature, Chamber Temperature and comparison of Time domain specifications

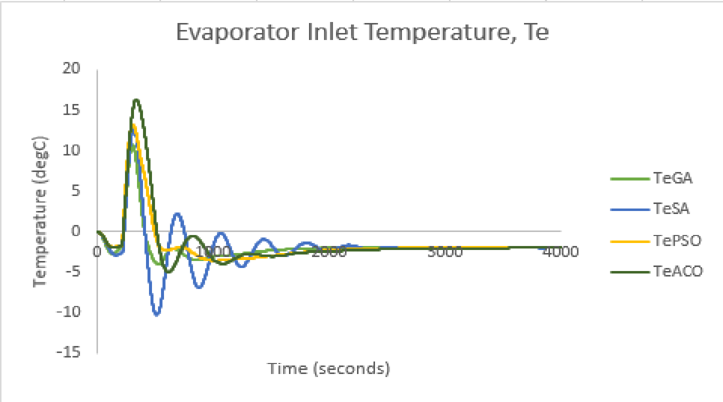


Fig.6. Closed Loop Response of Evaporator Inlet Temperature Te (in degree Celsius)

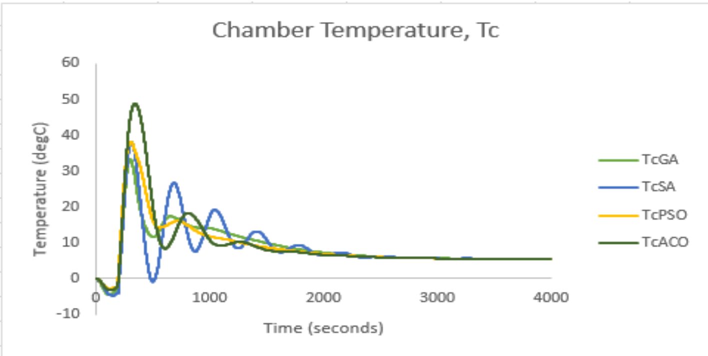


Fig.7. Closed Loop Response of Chamber Temperature Tc (in degree Celsius)

Time domain specifications for the system based on the specified controllers have compared and suitable controller will be determined. The comparison of time domain specifications shows that Genetic Algorithm based PID controller is suitable for the given cold storage system with less settling time.

Table 1. Time domain Specifications for Te

Parameters	Time domain specifications	SA based PID	GA based PID	PSO based PID	ACO based PID
Evaporator inlet Temperature Te	Rise time(sec)	120	110	110	140
	Peak Overshoot (%)	12	10	12	15
	Settling Time (sec)	2700	1800	2300	1900
	ISE	2.72e4	1.57e4	3.32e4	5.32e4

Table 2. Time domain Specifications for Tc

Parameters	Tim domain specifications	SA ased PID	GA based PID	PSO based PID	ACO based PID
	Rise time(sec)	250	200	250	220
Chamber Temperature Tc	Peak Overshoot (%)	30	30	27	34
	Settling Time (sec)	2800	2700	3000	2700

5.2. Output Response for Power consumption and comparison of Time domain specifications

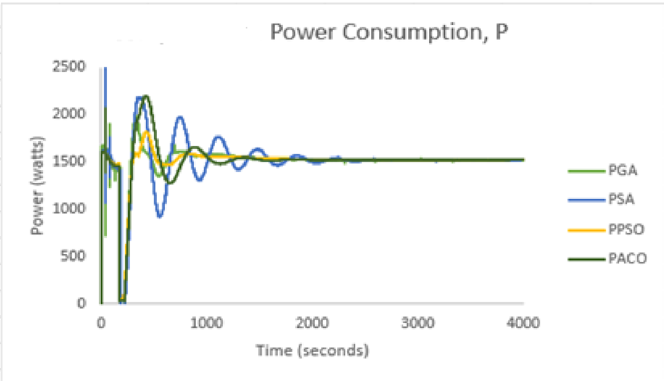


Fig.8. Closed Loop Response of Power Consumption P (in watts)

Time domain specifications for the system based on the specified controllers have compared and suitable controller will be determined. The comparison of time domain specifications shows that Genetic Algorithm based PID controller is suitable for the given cold storage system with less settling time.

Table 3. Time domain Specifications for P

Parameters	Time domain specifications	SA based PID	GA based PID	PSO based PID	ACO based PID
	Rise time(sec)	230	150	200	190
Power Consumption P	Peak Overshoot (%)	5	1.3	5	6
	Settling Time (sec)	1700	800	1500	1100
	ISE	3.23e4	1.58e4	1.52e5	2.29e5

5.3. Energy consumption and cooling cost calculation

Let,
Hours of Operation = 24, Watt usage of hour = 1524, BTU per hour = 1047, Costs per kWh = Rs.5

Calculation of energy consumption cost done by the formula,

$$\left(\frac{Hours\ of\ Operation*Watts\ usage\ of hour}{1000}\right)*cost\ per\ kWh \tag{10}$$

Energy consumption = 36.57kW

Energy Consumption cost = Rs. 182 per day

Calculation of cooling cost done by the formula,

$$\left(\frac{Hours\ of\ Operation*BTU\ per\ hour*0.293}{1000}\right)*cost\ per\ kWh \tag{11}$$

Cooling Cost = Rs. 36.81 per day

6 Conclusion

The main aim of the work is to study the dynamic behavior of the Evaporator inlet temperature Te, Chamber Temperature Tc and Power Consumption P of the compressor during the storing of fruits and vegetables. The calculation of energy consumption and cooling costs have done. The open loop response of the cold storage system has done. The control of the output parameters have done by optimization techniques such as Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) for tuning of Proportional Integral Derivative (PID) Controller. The evolutionary based algorithms for the given cold storage system provides reduction of the impact of environment and improvisation of economic benefits for small-scale cold storage unit. The time domain specifications for the obtained output responses have compared and the suitable controller has obtained. The suitable controller for the given cold storage system is the **Genetic Algorithm based PID controller**.

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