**American Journal of Engineering Research (AJER)**
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-2, pp-142-146
www.ajer.org
Research Paper Open Access

# Optimize the Schedule of Refrigeration System by Harmony Search Algorithm

Chun-Wei Chen
*Huizhou University, 46 Yanda Road, Huizhou, Guangdong, P.R. China 516007*

***Abstract***
*This study employs the Harmony Search Algorithm to determine the optimum operation of each refrigerant compressor unit within the refrigeration system to obtain the most energy-saving operation for maximum operation efficiency of the system (energy consumption efficiency), according to the actual required refrigeration capacity at load side, actual performance and operation condition of each unit. The results reflect that the Harmony Search Algorithm can obtain the optimum solution and increase the coefficient of performance of the original refrigeration system by 7.5%.*
***Keywords:*** *refrigeration system, energy optimization, schedule, harmony search algorithm, coefficient of performance*

---

Date of Submission: 06-02-2024 Date of acceptance: 19-02-2024

---

## I. Introduction

The refrigeration system must be designed to meet a range of frozen needs, particularly in Taiwan, which has four distinct seasons and refrigerated and frozen storage needs to adapt to various changes. The refrigeration system must operate in a permissible range by changing operation points so as to provide different refrigeration capacities, eventually satisfying different needs. Therefore, in common designs, multiple refrigerant compressor units are used to produce the required refrigeration in a 'flexible' manner.

Traditionally, the operation of refrigerant compressor units is controlled only by experience or PID controllers of refrigerant temperature or pressure; the DDC is used for setting and adjusting the operational status of each compressor in the system. Due to the lack of scientific, systematic and optimum logic basis, it is difficult to optimize the operation of the refrigeration system and control the excessive energy consumption with these methods. An advanced control method requires the establishment of an appropriate refrigeration system model by which the dynamic action of the system can be resolved and based on which the optimum control strategy can be designed to maintain the system at the optimum operating point. While researches on optimum control strategy are still few, due to the complexity of the refrigeration system, establishing a model for optimum operation control and solving it further still remains a subject of research.

Based on the above considerations, this study proposes a new control mode to maximize the operation efficiency of the refrigeration system, i.e. energy usage efficiency by using the HSA for system optimization technology, considering the actual required cooling capacity at load side as the basis of operation adjustment of all components in the system and considering actual performance and operation condition of each component. The model will determine the optimum operation mode (schedule) for each component with its optimization logic and algorithm so as to achieve the optimum COP of the refrigeration system when the refrigeration capacity of refrigerated and frozen storage is satisfied.

## II. Operation Schedule for Energy Optimization of Refrigeration System

### 2.1 Energy Optimization Control Mode of Refrigeration System

The optimum operating strategy goal of the refrigeration system is to control the operational status of each compressor unit so as to maximize the average COP after the system runs for some time and satisfies all operating restrictions. From the mathematical perspective, this control can be described as a system optimization control model. Fig. 1 is a diagram of a typical refrigeration system operation. This study proposes a new control model 'energy optimization control model of refrigeration system' based on this operation framework to maximize operation (energy) efficiency of the refrigeration system, by employing the mathematical modeling optimization programming from system optimization method and considering the refrigeration capacity actually requested by the refrigerated and frozen storage and true operating performance and operation conditions of each unit as demand restrictions. On this basis, the operational status of each compressor unit in the system is optimized, thus achieving the optimum system performance. The mathematical model is established as follows:

***Objective Function:***

$$Max.\quad COP = Q * \left(\sum_{U=1}^{n} PC_U\right)^{-1} \tag{1}$$

$$Max.\quad R_{S,\ on\text{-}line}(t) = \prod R_{U,on-line}(t) \tag{2}$$

***Subject to:***

$$\sum_{U=1}^{n} M_U \left(RH_{outlet,U} - RH_{inlet,U}\right) \geqq Q \tag{3}$$

$$RT_{outlet,U} = RT,\ when\ M_U \neq 0,\ U=1, 2, 3, 4 \tag{4}$$

$$RP_{outlet,U} = RP,\ when\ M_U \neq 0,\ U=1, 2, 3, 4 \tag{5}$$

$$M_{min,U} \leqq M_U \leqq M_{max,U}\ ,\ when\ M_U \neq 0,\ U=1, 2, 3, 4 \tag{6}$$

$$PC_U = 0,\ when\ M_U = 0,\ U=1, 2, 3, 4 \tag{7}$$

$$R_U(t) = exp^{-\lambda Ut},\ when\ M_U \neq 0,\ U=1, 2, 3, 4 \tag{8}$$

In formula (1), we set the first set of objective functions to pursue the maximum operating COP of the system's on-line refrigeration compressor unit. In formula (2), we set the second set of objective functions to pursue the maximum operating reliability of the system's on-line refrigeration compressor unit. Equation (3) is a limiting condition. Here we set the sum of the refrigeration capacity provided by each compressor unit to meet the total refrigeration load required by the case refrigerated warehouse to ensure that the load end can obtain sufficient cooling energy. Equation (4) is a limiting condition. Here we set the refrigerant temperature at the outlet of the operating compressor unit to be equal to the given refrigerant temperature to ensure that the supplied refrigerant conditions meet the system requirements. Equation (5) is a limiting condition. Here we set the refrigerant pressure at the outlet of the operating compressor unit to be equal to the given refrigerant pressure to ensure that the supplied refrigerant conditions meet the system demand. Equation (6) is a limiting condition. Here we set the refrigerant mass flow rate of the operating compressor unit to be between the upper and lower limits to ensure that the compressor unit can operate normally. Equation (7) is a limiting condition. Here we set that when the compressor unit is not assigned any refrigerant flow rate, the unit is in a stopped state and its operating power needs to be 0 to avoid operational "contradictions" in the mode. Equation (8) is a limiting condition. Here we set the reliability of the operating compressor unit to a given calculated value. This will ensure that the operational reliability of the overall refrigeration system can be effectively estimated.

Based on the above, the "refrigeration compressor unit optimal control decision analysis model" established by this research will automatically determine a set of optimal compressor start-stop modes (which units should be on-line; which should be off-line) and the respective required refrigerant mass flow rate states of its on-line units to achieve the goals of equations (1) and (2) and satisfy equations (3)-(8) to achieve the goal of "economic operation".

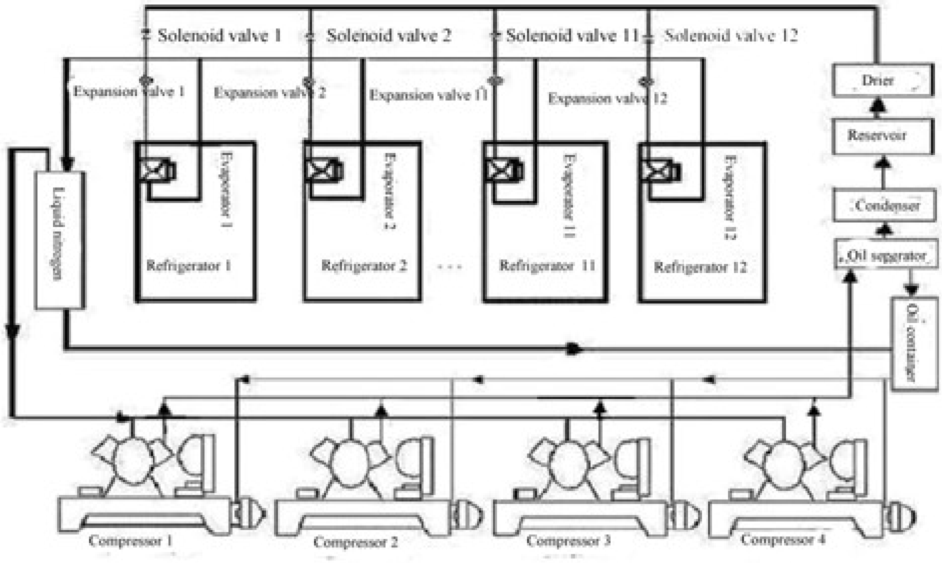


Fig. 1: Operating Diagram of a typical Refrigeration System

**2.2 Search Algorithm for Mode Solution Optimization**

Harmony Search Algorithm has been proposed by Geem et al.(2001). It is a meta-heuristic algorithm based population that models the effort of catching harmony among the sounds of musical instruments. The pitch of a musical instrument determines its harmony quality. Similarly, for an optimization problem, the fitness function determines the importance of decision variables. If the musician gets good harmony, she/he will record it in her/his memory. Likewise, if the algorithm achieves better fitness value, it stores this value in harmony memory. Using these similarities, Harmony Search Algorithm has been designed for optimization problems. Due to its random-based operators, Harmony Search Algorithm is an intuitive method that is fast to operate and easy to design.

In Fig. 2, the flow diagram of Harmony Search algorithm is given. As shown in the figure, the algorithm starts with the creation of the parameters and the harmony memory (HM) according to the problem parameters. The HM is initially filled with random values that are compatible the parameter boundaries. At the same time, the objective function appropriate for the problem is determined. At this stage, if it is a constrained optimization problem, a method is chosen related to how the constraint function will be effected on the objective function. Then, a new harmony is generated in three ways. These ways are harmony memory consideration rate (HMCR), pitch adjustment rate (PAR) and random selection. If the obtained new harmony is better than anyone in HM, the new harmony is stored instead of the worst harmony in HM. Unless the termination conditions are met, the process of creating new harmony and if necessary, the process of updating the HM is repeated.

In this study, the maximum iteration of HSA is set to 10,000, HMS (Harmony Memory Size) is 100, HMCR (Harmony Memory Consideration Rate) is 0.95, Min PAR (Pitch Adjustment Rate) is 0.3, Max PAR (Pitch Adjustment Rate) is 0.95, Min bandwidth is 0.0001, and Max bandwidth is 1.0.

## III. Case analysis and results

This study conducted relevant tests and analyses on the refrigeration system of a fruit and vegetable market under operation by the Farmers Association in central Taiwan. The refrigeration system is simultaneously operated by four 30-HP reciprocating compressor units to provide a sufficient amount of cold energy for 12 refrigerated warehouses. Each compressor unit has a rated cooling capacity of 20 RT and uses R-22 refrigerant. Currently, the number of compressor units of the refrigerated warehouse is set according to the following simple rules:

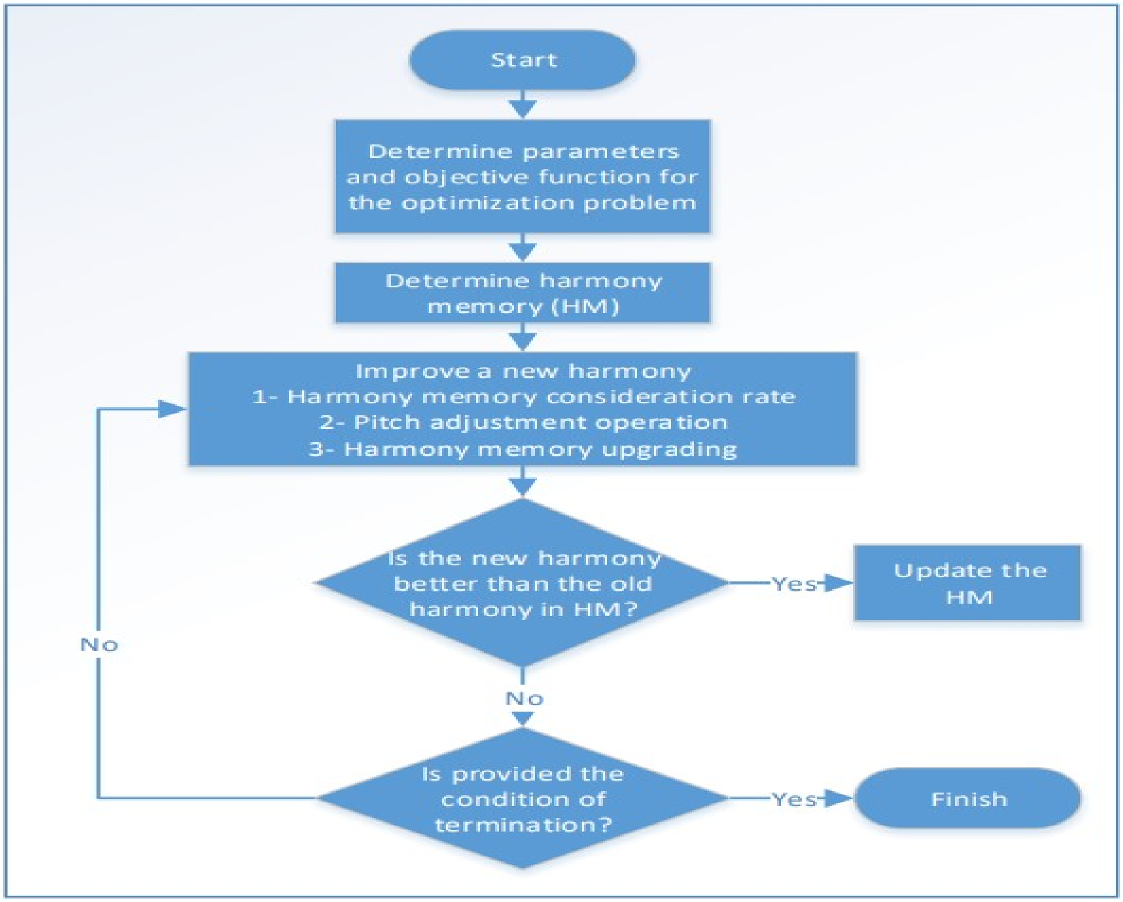


Fig. 2: The flowchart of Harmony Search Algorithm

- When cooling 1–3 chambers, one compressor should be operating.
- When cooling 4–6 chambers, two compressors should be operating.
- When cooling 7–9 chambers, three compressors should be operating.
- When cooling 10–12 chambers, four compressors should be operating.

The control rules indicate that one compressor can supply a cooling load sufficient for three refrigerating chambers. The ON/OFF switching of the compressor is controlled through the interface module of the main monitoring computer in the control room. The on-site operator determines the operation settings of the specific compressor unit (or multiple units) according to the operator's experience and preference.

This study collected data from the studied case, including operation data of the refrigeration system, operation modes, hourly cold energy requirements during the test period, and related restrictive conditions. In accordance with the aforementioned methods and procedures, the collected data were used to construct a program and interface for the optimal control decision of the optimal control decision analysis (support) system for the refrigeration system of the studied case. The program and interface were based on the associated inverted neural network model, nonlinear mathematical planning, and the principle and solution of the Harmony Search Algorithm. Borland C++ Builder (BCB) 6.0 produced by Borland was used to construct the related programs and interfaces. The system mainly consisted of database modules for data transfer (input) and storage as well as modules such as model library modules and human–machine interface modules for calculation, analysis, and simulation.

Fig. 3 reveals the comparison results of COP before and after optimization of compressor units of 2022.11.01–2022.11.30 refrigeration system. The average running COP prior to system optimization is 3.87. However, after optimization with 'energy optimization control model of refrigeration system' established in this study, the simulated result reveals that the average COP increases to 4.16 with an average energy saving rate of 7.5%.

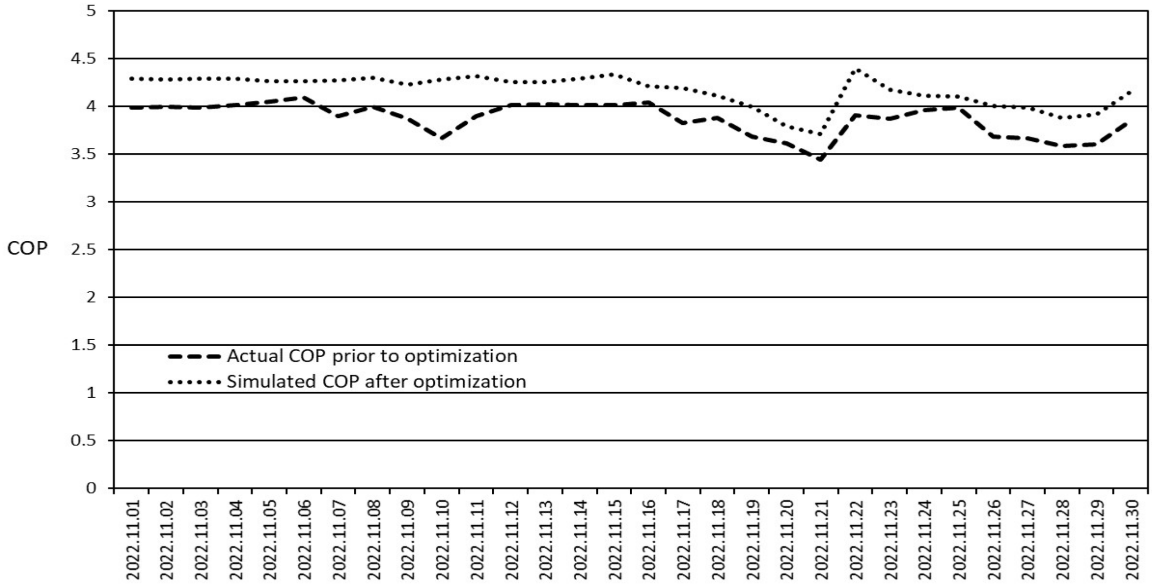


Fig. 3: COP comparisons before and after refrigeration system optimization

## IV. Conclusions

According to the simulation results, we observe that these results are consistent with our expectations and constraints; therefore, mathematical modeling optimization and Harmony Search Algorithm (HSA) can greatly promote the operational performance of the refrigeration system. The conclusions are as follows:

(I) The 'energy optimization control mode of refrigeration system' with HSA can determine the optimum operational status of each component within the system (including component start/stop status and refrigerant flow rate), without changing the existing component or influencing the cooling quality, i.e. maintaining an equal cooling ability, in order to obtain better energy efficiency.

(II) The new mode achieves a more exact match for actual refrigeration system operation, and provides a more precise mathematical result when obtaining highly precise data on required parameters and functions of the new mode.

(III) The method that employed the HS algorithm exhibited optimal effectiveness (efficiency) and was determined to be a comprehensive and operation-friendly solution model.

## References


[1]. A. J. Ardakani, F. F. Ardakani, S. H. Hosseinian. (2008). A novel approach for optimal chiller loading using particle swarm optimization. Energy and Buildings, Vol. 40, pp. 2177-2187.

[2]. Fu-Ann Lin. (2003). Branch-and-Bound Method for Optimal Chiller Sequencing. Master Thesis, Taiwan.

[3]. Chun-Wei Chen, Cheng-Wen Lee and Chia-Yon Chen. (2010). To Enhance the Energy Efficiency of Chiller Plants with System Optimization Theory. Energy and Environment. 21(5): 409-424.

[4]. R.J. Dossat. (1991). Principles of Refrigeration. Wiley, U.S.A.

[5]. J. Zhang and E.A. Gro. (2000). Saving Energy in Refrigerated Warehouses. ASHRAE Journal, 42(8), 35-39.

[6]. Geem Z. W., Kim, J. H., & Loganathan, G. V. (2001). A new heuristic optimization algorithm: Harmony search. SIMULATION: Transactions of The Society for Modeling and Simulation, 76(2), 60-68.

[7]. Geem Z. W. (2009). Music-inspired harmony search algorithm. Berlin, Germany: Springer.

[8]. M. S. Bazaraa, H. D. Sherali and C. M. Shetty. (1993). Nonlinear Programming Theory and Algorithms. John Wiley & Sons Inc., U.S.A.