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NEURAL NETWORK AND MODEL PREDICTIVE CONTROL FOR SYNCHRONOUS GENERATOR SYSTEM

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Master's Thesis

Supervisor

Asst. Prof. Dr. Mesut ÇEVİK

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DEDICATION

Asst. Prof. Mesut EVIK has been supportive and generous throughout my master's thesis. His studentship was enjoyable.

My thesis is dedicated to my parents, who gave me everything to be here, succeed, and be a good person.

My brothers and sister have always respected what I wanted to do and encouraged me. I value your love.

This thesis is also dedicated to my many supportive friends. I'll always appreciate their work.

ABSTRACT

NEURAL NETWORK AND MODEL PREDICTIVE CONTROL FOR SYNCHRONOUS GENERATOR SYSTEM

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Today's recovery in the whole world seems to come with the high momentum towards electrical energy as a direction of industrialization. This project, which is electricity generation, is the right choice of generators used as backup and industrial facilities, which are a more important part of facility expenditures.

In this study, new method based neural network technique LSTM and particle swarm optimization algorithms presented to deal with this problem. The aim of this study predictive control for synchronous generator system. In the first stage, several techniques such as support vector machine, random forest, and decision tree applied to this problem. Then, the obtained results are not suitable which lead us to developed new technique-based LSTM. The results of classical LSTM obtained and then the LSTM based PSO applied to deal with this problem which is new study. The obtained results are compared and show that the proposed LSTM based pso is best than other studies.

Keywords: Neural Network, PSO, Predictive Control, Synchronous Generator System.

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ABBREVIATIONS

GA	:	Genetic algorithm
GWO	:	Grey wolf optimizer
ACO	:	Ant cony optimization
PSO	:	Particle swarm optimization

1. INTRODUCTION

Today, electrical energy is mostly produced in hydroelectric, thermal, renewable power plants and nuclear power plants. Traditional generator types are rotating electrical machines such as direct current generator, asynchronous and synchronous generators. The design programs developed in recent years and the structural solutions realized in the designs produced accordingly have enabled the production of generators with different structures in a wide range from small to large powerful. The developments in magnet technology are of great importance, especially in the widespread use of permanent magnet synchronous generators [1]. However, permanent magnet machines are more expensive than conventional synchronous machines. This is because magnet materials are scarce and costly to manufacture. With increasing energy costs and worldwide environmental protection trends, using motor-generator systems to produce economical and ecological electrical energy is the most important agenda of the industry and energy sector. Pure and clean electrical energy production is very important in the energy sector, as well as in the automotive and shipbuilding sectors. The best way and high performance of energy production has recently become possible thanks to the developments in power electronics. Recently, the use of permanent magnet DC motor-synchronous generator system in motor-generator systems has increased. Permanent magnet synchronous generators are especially used in low-speed applications. It is desired that the high-performance drivers used in these systems are not affected too much by parameter changes and that the output voltage is at the desired amplitude and frequency. For these drive systems to work under the desired conditions, a control technique must be added to this system [2]. In industrial and energy sector applications, the voltage supplied from the generator to the load and accordingly the power are controlled by the drivers used to control the motor-generator systems. For this, it is desired that the motor speed settles to the reference speed in a short time. PI and PID control systems, which are traditional control systems, are sufficient in small power applications. Especially in small power applications, using an inverter system with uncontrolled rectifier and sinusoidal PWM to keep the output voltage of these systems at the desired frequency and amplitude provides advantages both in terms of cost and in terms of control of the system. While permanent magnet synchronous generators are driven by any turbine, driver systems including uncontrolled rectifier-PWM inverter can be used to control the output voltage. Considering that motor-generator systems can be used in many areas with the development of the developed control techniques, studies have been carried out on these issues in the literature in recent years.

They are the most critical equipment in tools and electronic systems of protection and training systems. In electrical systems, design and software in artificially artificial systems will be completed regarding application and view, remote views, data monitoring. Today, electronic protection software also becomes more complex depending on different input, scenario scenarios and a stack of code to be in place for protection. For example, in a medium security function, only the "parametric protection" function is in place within the standard one, while a different function is included in this function area. system consists of the best system. Such a high number can be applied.

The inadequacy of classical control methods in eliminating dead time in systems, overcoming time delays and constraints in multivariate systems played an important role in the development of predictive control. It was first proposed by the French engineer Richalet in 1978 under the name Model Predictive Heuristic Control (MPHC) and was used in practice at the petrochemical institute in the late 1970s. Model Predictive Control is based on the direct use of the system model and the method of minimizing the control signal of the system according to an optimal criterion. By default, predictive model control uses current and previous system inputs to calculate the next system output. To minimize the error between the output signal of the system and the reference value, the most suitable sequence of control (input) signals is calculated and applied to the system. In a nutshell, a model predictive controller is a controller that calculates the necessary control sequences to optimize the future behavior of the system. Divergent horizon management strategy is used to predict future results. The sliding horizon method is the principle of moving the horizon into the future at each moment of sampling and applying to the system the first element of the command sequence it had. Model predictive control was used in industry in the 1980s and was first used in low-speed processes such as the petroleum, chemical, and petrochemical industries. Improvements in microprocessor technology have led to their future use in high-speed systems such as robotic systems and power systems. After the research published in the literature by Richard, the rapid development of science was revealed. In 1979, Cutler and Ramarker conducted a new study called Dynamic Matrix Control. In this study, the objective function was obtained by quadratic planning according to the finite prediction range, and the system was modeled using a step response model. Dynamic Matrix Control was the first example of predictive control in practice. In 1987 Clarke developed the "Generalized Predictive Control" method. This method was developed in discrete time and the continuous time design of these 2 methods was made by Demircioğlu and Gawthrop in 1991 [3].

The term model predictive control (MPC) does not essentially refer to a specific control strategy. MPC is a general term for various control strategies (MAC, DMC, GPC, etc.) that use a system model to generate control signals to minimize an objective function. Key features of these methods include incorporating an internal model, applying the sliding horizon principle, and calculating control signals based on the expected response of the system. The difference of MPC technology lies in the type of internal model used to calculate the objective function and the controller. The MPC model predicts the change in the dependent variable of the simulated system from the change in the independent variable. The system noise model uses an explanatory variable that cannot be set by the controller, and other process variables define the controller's objectives or system process constraints. MPC uses the process model, the current dynamic state of the process, and current measurements [4]. The advantages of predictive control technology, which has many applications today, can be summarized as follows:

a. predictive control allows intuitive identification of systems and easy adjustment of control parameters, making it easy to implement even when system information is limited.

b. It can be used in many applications from systems with simple dynamics to complex dynamics (such as systems with a phase shift, systems with no minimum phase).

c. It can be easily applied to systems with many state variables.

d. It can struggle with the dead times of the systems.

e. Since it works like a feed forward control, it has the effect of damping measurable noises.

f. The obtained controller is quite suitable for applying the linear control law.

g. It is very useful and useful if future setpoints are known. The disadvantages of this control strategy are.

h. In cases where the system dynamics does not change, the parameters of the controller can be found beforehand. However, as in the adaptive control, the processing load is quite high, as the control gains will be recalculated according to the system input-output in each step-in model predictive control.

i. As the difference between the mathematical expression of the system and the real system increases, the accuracy of the predictions of the system's future inputs and outputs will decrease, and it will be difficult for predictive control to operate within the desired performance range.

In the Model Predictive Control algorithm, there are various methods to obtain and express the required models. Some of these methods are as follows.

a. Step response model
b. Impulse response model
c. Transfer function model
d. State-space model

The main idea of the step response model is to apply a unit step input to the input of the system and obtain the open loop response. This model is sufficient only if all parameters of the system can be measured, otherwise an observer is required to predict unmeasurable variables.

There are many Model-Based Predictive Control algorithms developed. There are different models used in these algorithms. One of the most widely used models is the step response model. The reason why this model is widely used is that when step input is applied to the system, measuring the system output is sufficient to find the model parameters. Another advantage of this model is that it can also be used for multivariate systems. This model consists of many parameters and can only be used in stable systems as open loop. The Impact Response model is very similar to this model. In the Pulse Response model, the model parameters are found by applying pulse input to the system. The transfer function model is the most common model in the academic world and is used in most controller design methods, since the number of parameters is low and suitable for all kinds of systems. The state space model is used in some algorithms because it can easily describe multivariate systems. By transferring the concept of state space to Model-Based Predictive Control theory, it enabled more complex problems to be addressed, such as the presence of random disturbances in the measured variables. Optimization is an important issue in the development of Model-Based Predictive Control methods. If the criterion is quadratic, the solution can be expressed as a linear function based on past inputs and outputs and future inputs. In case of limitations, the solution can be obtained with iterative approaches that require more processing. Model-Based Predictive Control techniques differ from each other in terms of the model used and the selected performance criteria. Below are some basic Model Based Predictive Control techniques:

a. Dynamic Matrix Control (DMC): This method was first used by Shell in 1973. In this method, step response model is used. Using this algorithm, the "Quadratic Dynamic Matrix Control (QDMC)" method, which takes into account the limitations in system inputs and outputs and uses 'quadratic' programming, has been developed. This algorithm is also suitable for the discrete state space model.

b. Model Algorithmic Control (MAC): This algorithm uses the impulse response model, which is only suitable for stable systems in open loop. The algorithm minimizes the difference between the output of the system and the input trajectory obtained as a first-order system.

c. Generalized Predictive Control (GPC): A square performance measure including control power at a desired weight and ARMAX("Auto-regressive moving average with exogenous variable models") model is used. In the absence of constraints, there is an analytical solution. Among these methods, Dynamic Matrix Control and Generalized Predictive Control are the most used methods. Some of the advantages of Model-Based Predictive Control over other control methods can be listed as follows.

    a. It appeals to workers with limited control knowledge as the concepts are intuitive and at the same time parameter settings are easier than other methods.
    b. It can be used in the control of a wide variety of processes, from very simple dynamics to more complex dynamics such as unstable, non-minimum phase, very long dead time processes.
    c. It can be used in the control of multivariate systems.
    d. It has the feature of eliminating the dead time effect.
    e. A linear control rule is obtained that is easy to apply.

f. It is very useful and useful when the prelude to the future is known.
g. It is a completely open method based on certain basic principles

1.1 PURPOSE OF THE THESIS

In the study, these study areas can also be used on equipment used in electrical systems of similar facilities used in ANNs and an alternative to existing electronic protection systems may become possible. It is designed in more detail than for electrical use. The proposed method combined the ANN famous type LSTM to estimate the control of the generator. The grid search plying great role in the enhancing the parameters of the LSTM. Based on the definitions above, the fact that electronic control systems are becoming more and more widespread day by day and this issue has become an important issue in smart grids shows that breaker systems used in our homes and industries will tend to such designs more in the medium and long term. Especially with the increase of energy transmission lines and renewable energy sources, it is obvious that the energy needs to be reconsidered in the grids and controlled with more statistical and fuzzy approaches. Each network does not show the same characteristics and all of them have their own power values, harmonic values and power factor values. Since the increase in renewable energy also creates the need for cogeneration, energy is no longer a one-way variable. In this way, all electrical network systems become more complex and become living organisms with new modifications constantly. The fact that the systems can easily communicate between themselves from every access point, that the general characteristics of the networks can be learned and that their operating behaviors can be learned, have a very important place in terms of the healthy operation and easy control of the network. From this point of view, in the thesis, a hardware and software design on a micro scale, which is completely electrical and software learning and control, has been made with a predictive approach. This design can also be evaluated on a macro scale in future projects, and the common point of all these systems is a self-learning and controllable ANN modeling. An artificial neural network is used in the basic structure and an embedded software is used in the logical unit of the circuit. Analogue information coming from the network to the microcontroller is analyzed as data sets and embedded in a basic learning algorithm, and then the system, which goes into normal operating mode, is allowed to quickly detect information with radical characteristics. In general, the semiconductor technology used in motor protection and motor drive systems has replaced the switch system of an automatic fuse in this design, and the control is provided by this semiconductor switch being in transmission or cutoff. The benefit of this or a similar intelligent protection system to the existing technique is that the short circuit current can be detected before it reaches its peak, and it can accommodate many protections such as harmonics, voltage interruptions, short-term overvoltages, leakage currents, in the same structure, apart from 22 short circuits in the network. In the second part of the thesis, the simplified block diagram of this design and the general working structure of the system will be mentioned, and the circuit and software structures will be examined in sections. In the next step, the detailed structure of the software working with artificial neural network, which is the main subject of the thesis, will be covered

1.2 HYPOTHESIS

n order to determine the unusual operating conditions, the basic current and voltage data in the network are examined by using the backpropogation algorithm, and the usual sensitivity of these data is determined by numerical methods. During this determination, the general behavior of the network, its sensitivity to current and voltage magnitudes are carried out according to the relevant training algorithm, and the fastest number of reaching the target is determined. In the operating mode, the radical or non-radical tendencies of the system against this normal operating sensitivity are determined, and it becomes possible to protect the system automatically as soon as the detection of radical data.

1.3 CONTRIBUTIONS

This study presented several contributions:

i. This study presented new method by combining LSTM with PSO to estimate the synchronous generator system values with high estimation rate.
ii. The proposed method presented fast model that perform remarkable results.
iii. The proposed method compared with several techniques to evaluate the results and show that the proposed method is best.

2. LITERATURE REVIEWS

2.1 SURVEY

In their study, Sanchez et al. explained the basic principle of model predictive control over discrete time representation. In this study, they also focused on adjustable predictive control and gave application examples [5]. Comacho and Bordon explained the techniques used in the predictive control method in their studies and talked about the prediction algorithms used in practice [6], [7]. Clarke et al. mentioned generalized predictive control for the first time in this study. They explained the basic principles of generalized predictive control [8]. Holkar and Waghmare explained the basic principles, historical development and formulations of Dynamic Matrix Control, Generalized Predictive Control, Model Algorithmic Control, Extended Self-Excited Control, Extended Excitation Sliding Horizon Control and Predictive Functional Control [9]. In this study, Liuping Wang made advanced simulation of model predictive control with Matlab codes. He demonstrated the application of various optimization methods to predictive control. He demonstrated the generation of State Feedback Predictive Control matrices [10]. Morari and Garcia summarized the state space representation of model predictive control. They developed a predictive control method using the state estimation method and based on the step response technique[11]. Clarke and Mohtadi examined the relationship between generalized predictive control and linear quadratic programming. They examined the effects of the prediction horizon and the control horizon on the system [12]. In this study, Kwon and Han summarized the Floating Horizon Predictive Control technique. They demonstrated successful feedback techniques used in many applications. They explained the most suitable control methods such as LQ, H-infinity, LQG, H2 [13]. 3 Morari and Lee summarized the historical development of predictive control in this study. They especially focused on the development of optimization techniques used in prediction algorithms [14]. In this study, Richalet examined the usage areas of Model-Based Predictive Control in the industry. The feedback-feedforward method has explained problems such as overcoming the restriction problem by using the "crude oil distillation tower system" [15]. Muske and Badgwell performed disturbance modeling for free-balanced linear model predictive control. They examined the unmeasurable disturbance effects affecting the inputs, states and outputs of the system [16]. Gabriele and Kerrigan examined the free-balanced sliding horizon for linear systems with predictive control constrained in their study. For this, they designed a dynamic state feedback sliding horizon controller and examined the behavior of the system by taking into account unmeasurable disturbance effects [17]. Koerber and Rudibert performed a combined feed-forward-feedback control of wind turbines using the State-Constrained Model Predictive Control technique. In their simulation study, they examined the state constraints in three situations as normal state, grid losses and gusts. In all these cases, they showed that model predictive control overcomes the constraints [18]. In this study, Morari et al examined the Restricted Robust Model Predictive Control technique using linear matrix inequality. They examined situations such as time delay, disturbance effect, reference point tracking, reference trajectory tracking in the controller they designed [19]. Fend et al. studied constrained predictive control with simultaneous estimation using wavelets. They evaluated the future and current outputs of the system along a finite horizon by considering the constraints [20]. Kuo and Melsheimer designed a neural network-based model predictive controller and controlled the wastewater neutralization system. They used this control technique to adjust the pH value, which is the most important factor of neutralization [21]. Miguel and Setnes designed a fuzzy predictive filter for model predictive control. With this filter they designed, they aimed to eliminate the deficiencies between the calculation time of the system and the system performance. Multiplying it with a gain factor made this filter an adaptive control [22].

Mendonça et al. conducted a study on the fuzzy model in multivariate predictive control. In this study, fuzzy rule makers were arranged according to model predictive control. They also consider the constraints. They simulated the model on a container crane [23]. Jianfend et al. controlled the locomotive braking system using the T-S Fuzzy Model Predictive Control method. They used fuzzy sets for the initial conditions of the system. They carried out this study both as a simulation and as an application[24]. Ardalan, Stefanopoulou and Peng investigated current control in a hybrid fuel cell power system with a model predictive control approach. They used the distribution of current demand between ultracapacitors and fuel cells for predictive control [25]. Hredzak et al. designed a model predictive controller for a hybrid fuel cell and ultracapacitor power supply. With the controller they designed, they managed to operate the battery current, battery discharge status, ultracapacitor current and voltage within the specified limits [26]. Zhu and Lingfeng realized the intelligent control of the ventilation system with the CO2 prediction model for energy efficient buildings. The aim was to reduce the energy consumption rate and to keep the carbon dioxide amount in the building at the desired value [27]. Yudong et al. carried out a model predictive control study for the building cooling system. They designed a controller by modeling the building cooling system and thermal energy. Model predictive control calculated the thermal energy required using future values of weather conditions and building load demand[28]. As a result of their experimental study, they observed a reduction in electricity consumption and cost [29]. In their study, Yanhui et al. controlled the full-wave da-da converter with a predictive method. They aimed to reduce the fluctuations in the output voltage[30]. In this experimental study, they succeeded in reducing the fluctuations in the output voltage [31]. Florin and Lazar have stabilized a network-controlled system with a model predictive control method by applying on a direct current motor [32].

When these studies are examined, it is seen that the most important advantage of model predictive control over other control methods is that restriction problems are easily added to the system at the design stage. It has also been found to be more useful in multivariate systems than other methods. Its advantages over other methods can be listed as follows [30].

i. It appeals to workers with limited control knowledge, as the concepts are intuitive and at the same time parameter settings are easier than other methods.

ii. It can be used in the control of a wide variety of processes from very simple dynamics to more complex dynamics such as unstable, non-minimum phase, very long dead time systems. □ It can be easily used in the control of multi-variable systems.

iii. It has the feature of eliminating the dead time effect.

iv. An easy to apply linear control rule is obtained.

v. It is very useful and useful when the prelude to the future is known.

vi. It is a method that is completely open to development based on certain basic principles.

vii. It is very useful if the future reference is known. Comacho listed the disadvantages of Model Predictive Control compared to other methods as follows.

viii. In cases where the system dynamics does not change, obtaining the controller can be done in advance, but if adaptive control is performed, all calculation operations are repeated at each sampling time.

The most important problem is to obtain a suitable model for the system. Since the algorithm is based on obtaining the future system response by utilizing the system model, as the difference between the real system and the response increases, there are problems in obtaining the desired system response.

2.2 CONTINUOUS MAGNETS

Permanent magnets are materials that create a magnetic field without requiring excitation. Permanent magnets are usually made from alloys of elements such as iron, nickel and cobalt and have a wide B-H curve, high permanent magnet flux density (Br) and high magnetosensitivity (HcB) . The high permanent magnetic induction allows the magnet to withstand a stronger magnetic field than the core air gap. The first commercially developed magnets were Al-Ni-Co magnets. This magnet was made in 1935. Ferrite magnets were made in the 1960s and SmCo in 1975. The most recently developed magnet is the Neodymium Iron Horn (NdFeB). This magnet has the highest energy density of any commercial magnet [33]. According to Faraday's definition of basic flux density, the flux density of a permanent magnet consists of the arithmetic sum of two components. One of the components is caused by the presence of an external magnetic field and is the actual magnetizing force acting on the magnet. The other component is the natural component Bi, which is formed due to the ferromagnetic nature of the magnet. This component is the contribution of the magnetic material to the ambient magnetic field.

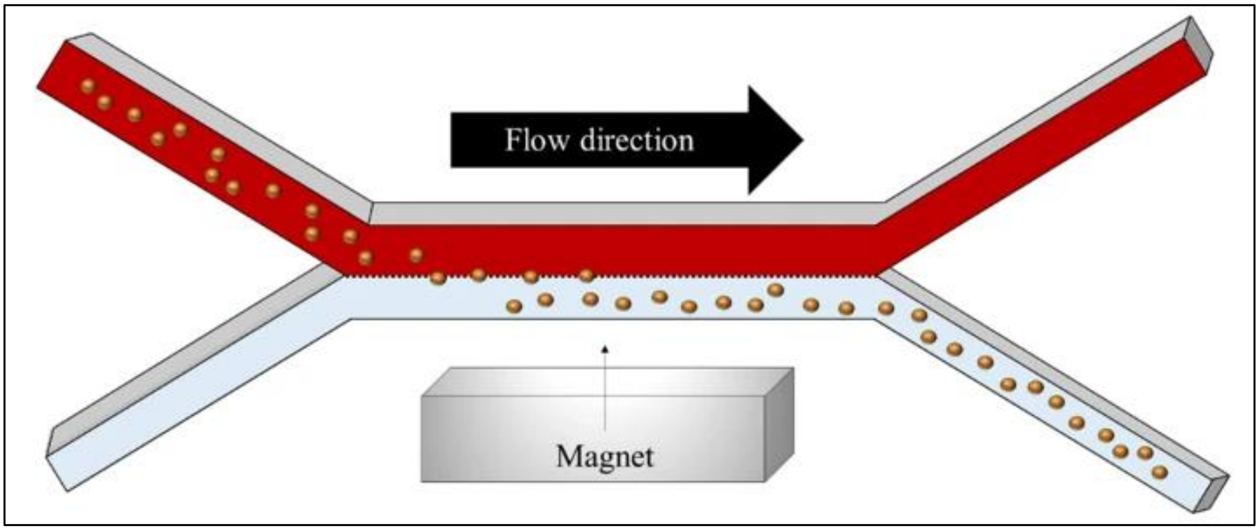

Figure 2.1: Simple Continuous Magnets

2.3 AN OVERVIEW OF CIRCUIT BREAKERS

Tüm elektrik sistemlerinde ve korumasında kullanılan devreler 6A geniş kapsamlı bir kontrolden 6300A geniş kapsamlı bir tasarıma sahip düşük gerilim, gerilim ve yüksek olmak üzere farklı elektriksel sistemde temel güvenlik ve işleme-kapama olarak kullanılanlardır. İlk devre devre sistemi sistemi SF6 deyimiyle AEG firmasından olması ve patentinden alınmıştır. 1951'de bu sisteme benzer başka bir tasarım Westinghouse firması tarafından üretilmeye başlanmıştır. Devre devrelerinin asıl olarak sanayide başlanması iki sene sonraki olan 1953 senesidir. Westinghouse tesisi tarafından tasarlanacak bu devre devre ürün 161kV'luk bir gerilime kadar 600A'lik fazılecek özellikte tasarlanmıştır. 40kA bir kısa devre kesme devresidir [34].

2.4 TRADITIONAL CIRCUIT BREAKING METHODS AND THEIR DISADVANTAGES

The basic solution in all circuit braking systems with a history of nearly 100 years is to cool the high-energy arc plasma, which occurs during short circuit or overcurrent, to discharge it from the cell. In order to achieve this, air, Co2 gas, SF6 gas, vacuum and oil cooling solutions have been adopted and used. The common point of all these designs is the use of arc extinguishing cells, the main content of which is iron, in the breakers. Arc extinguishing technology is based on ejecting the arc current up to 50,000 Kelvin from the plasma state until it is thrown out of the body by sweeping the electron cloud forward with an electromagnetic force and providing a rapid arc discharge. Considering the worst-case scenarios of the short-circuit moment, it has been seen that a bad short-circuit can last up to 10 ms, that is, one half mains frequency cycle. In low voltage distribution systems, an energy equal to at least 150.000A^2s emerges. In terms of energy use, this value corresponds to the heat energy generated by a long-range weapon used in ballistic weapon technology. During this high energy flow, resonances occur in the mains current and voltage, other protection and control equipment are exposed to short-term interruptions, and the energy of the equipment that protects the system from other aspects may be cut off. After the interruption or protection operation, the circuit breaker opens, but since the cause of the fault in the network is not known exactly, the long-term interruption is continued [35].

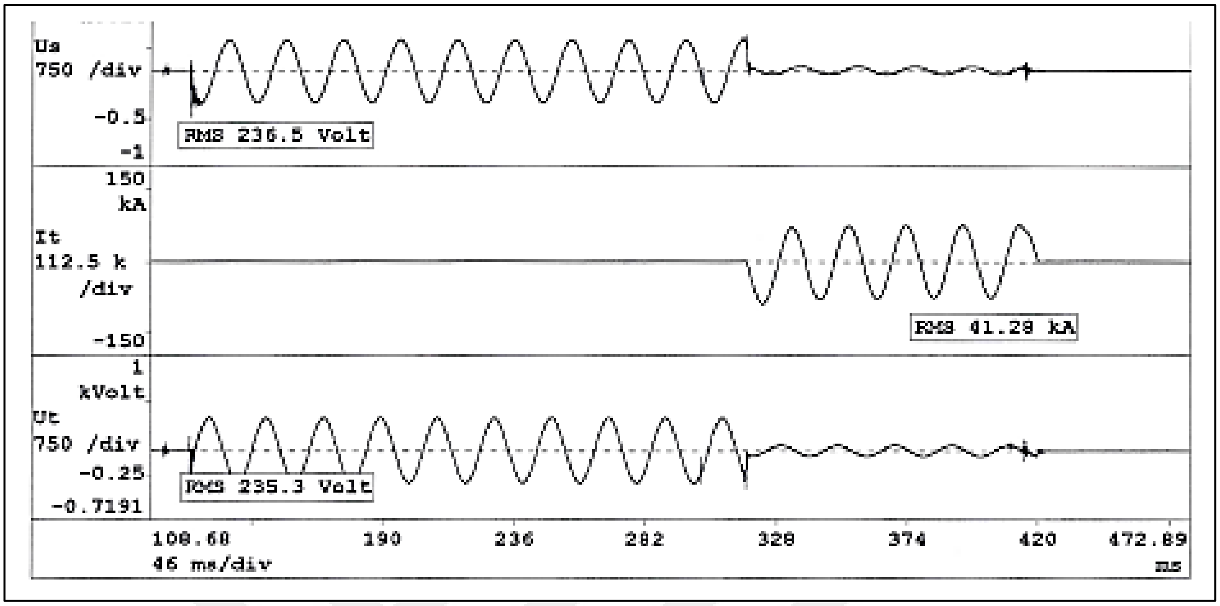

Figure 2.2: low-voltage breaker

2.5 USE OF HIGH TECHNOLOGY IN PROTECTION AND MONITORING SYSTEMS

With the frequent use of programmable logic controllers (PLC) in protection and control systems in industrial systems, the use of high technologies, especially in measurement, protection and control systems, has begun to take an important place as a result of the prevalence of electrical safety and control systems in networks. Today, many new technologies have been introduced for monitoring, measurement, control and protection within the general perspective known as smart grids, especially electronic protection systems have started to be used within the framework of SCADA technology, depending on the development of RTU and PLC and PC communication technologies over Modbus or LAN. .[36] A summary of the SCADA architecture is given in Figure 1.3, and it is clearly seen that the communication of basic sensors, working tools and hardware with each other has an important place in the architecture. Depending on the developing technologies, it is now possible to transfer and store all kinds of data via RTUs and PLCs. In this way, it is possible to transfer the information received from the control and protection relays as well as from the circuit breakers to the master device in a healthy way, and it is ensured that actions are taken for the information received through the human or machine interface on the opposite side. 20 All this communication network is made in real time and a control mechanism that can react instantly is formed. However, depending on the development of Internet technologies, it is possible to control a remote mechanism or sensor unit over IPv4. Depending on the increase in internet users in the world, the IPv6 address assignment system is developing, thus making it even more possible for industrial systems to communicate over the internet. (Internet of things = Iot technology)[36].

It is important to measure the electrical parameter values of the network today, where all instruments on the electrical network can be monitored and controlled via a controller or transducer. By obtaining power and energy transfer information from electronic meter reading systems, the basic energy orientation of the network can be determined, protection and control information can be analyzed according to the information received from electronic or electromechanical relays on the network, and analog and digital data obtained from PLCs and micro-electronic devices can be used in the facility or house. All devices can be controlled correctly. All these controls are provided by a master device or Human Machine Interface (HMI), and the control system gives an alarm, or the system continues to be used properly with new input variables. Today, it is estimated that the area of use in electrical facilities will expand as these technologies frequently find application areas.

2.6 INDUSTRIAL USE OF MODEL PREDICTIVE CONTROL

MPC is one of the most successful advanced control methods ever applied in industry [8]. Predictive control models were first developed by two major industrial research groups in the 1970s. According to Rishale et al (1978), MPHC (Predictive Experimental Control) and DMC (Dynamic Matrix Control) models were developed for Shell Oil (Cutler and Ramaker, 1980) in Adersa, France. The Clarke et al. Also (1987) received a lot of attention. One of the most important parts of predictive model management, the divergence horizon principle, was proposed by Propoi (1963). This model is very popular in industry, especially in the petrochemical sector and refineries, due to its predictive control, algorithmic simplicity, control system influence or sufficient gradual response mathematical model. . . According to the 2003 Model Predictive Control Study by Qin and Badgwell, as of the end of 1999, there are over 4,500 model predictive control applications in use worldwide. Unequal Constraints. Because of its success, predictive model control has become a popular topic in academic and industrial research [37].

2.7 QUAD TANK SYSTEM

Quad Tank System Quad tank system has complex dynamics which is very useful. Thanks to this feature, it has become one of the serious research topics in the field of control. Thanks to the dynamic characters of the system, the system transfer function has adjustable zeros. One of the zeros of the transfer function can always be in the left plane and the other in the left or right half plane. Due to its multivariate structure, the system exhibits a non-minimum phase behavior when appropriate adjustments are made. For these reasons, the quad tank system provides a good environment for researching different control technologies and advanced multivariate control technologies [38].

2.8 SOME MODELS USED IN THE INDUSTRY PREDICTIVE CONTROL TECHNOLOGIES

Rapid developments in control technologies have a wide-ranging impact on all control discipline areas. New theories, new controllers, actuators, sensors, new industries, new computing methods, new applications, new philosophies. Such developments present researchers with broader, rapidly expanding, and more advanced new research topics in the field of industrial control. Today's control software and technologies can offer more advanced control algorithms, but industrial engineers prefer durable and transparent process structures that can be made with simple controllers. That's why PID control structure continues to be the most used control technique in the industry, although there are very large and advanced structures in control theory. However, this approach has limits on good process performances. Model predictive control method, on the other hand, can interfere with the process control structure at different levels and address a wide range of process control constraints. For these reasons, MPC is the most popular of the advanced control technologies in industrial process applications. MPC was developed as a predictive function control technique for use in industry towards the end of the 1960s with its receding horizon structure. The receding horizon structure took place in the literature together with the state space model in the 1970s. Later, dynamic matrix control (DMC) in the 1980s and generalized predictive control (GPC) technique were developed in the following years[39]. There are many companies that use and develop model predictive control technology. Some of these are listed below with company names and technologies. Adaptive Predictive Control System (APCS) They have made model predictive control suitable for use in different purposes and in different fields. According to the results of the survey conducted by Qin and Badgwell in 1997, more than 2200 model predictive control applications have been made so far and it has been determined that their number has increased rapidly. The report shows that 67% of these applications were refining and distillation applications. Model predictive control has many applications in the petrochemical and chemical industries [40]. Significantly developing application areas are pulp and paper, food industry, aircraft and automotive industries. As Muske and Rawlings point out, current industrial MPC technology has some limitations. The most outstanding of them are;

As Muske and Rawlings point out, current industrial MPC technology has some limitations. The most outstanding of them are.

a. Models with Multiple Parameters: Many commercial products use the responses of pulse and step functions to multi-parameter processes for model identification. For example, while 3 parameters (coefficient, time constant and dead time) are sufficient to define the transfer function of a first-order process, more than 30 parameters are needed when defining a model with a step function. In addition, the model defined by the step function will not be suitable for unstable processes.
b. Tuning: It is not entirely possible to predict the closed-loop behavior of processes. Also, the limited set parameters make things even more difficult, and it is not easy to guarantee the closed-loop stability with the setting parameters.
c. Dynamic Sub-Optimizations: Some industrial solutions speed up the solution process by making sub-optimizations. In high-speed applications, the solution of the problem may not be applicable for every sampling time. Therefore, suboptimizations are made and suboptimization solutions are always close to the optimization solutions.
d. Model Uncertainty: Although model definition packages estimate model uncertainty, only RMPCT technology uses this information in control design. Although the relationship between performance and durability is not fully understood, the settings of other controllers become distorted when the durability is increased.
e. Constant Disruptor Assumption: Of course, the most reasonable assumption is to accept that the jamming signal will continue in the future. However, with better feedback information, disturbance signal distributions can be characterized.

f. Analysis: Regular and systematic analysis of the state and durability in the finite horizon formula of MPC is not possible. The standard closed-loop form cannot be represented with a time-varying control rule, especially if limitations exist. Technology continues to evolve and will continue to face problems such as model identification, ambiguous disturbance signal prediction, systematic improvement of model error, nonlinear model predictive controller design in future generations.

2.9 RUGGED MULTIVARIATE MODEL PREDICTIVE CONTROL (RMPCT)

RMPCT is a control system developed by Honeywell under the name Rugged Multivariate Predictive Control Technology. Each system aims to keep its output in the region and range determined by the upper and lower limits. If the value of the output is in this range, it is not penalized in any way. If an output goes out of the linearly determined reference trajectory, the output value changes to reach the nearest edge of the allowed region. The output variable is expected to go to the target region by following this trajectory. The time taken in this orbit by applying predictive outputs is between zero and twice the open-loop dwell time. Whenever the projected exit is outside the target region and the 'funnel' created by this trajectory, its distance from the funnel edge is defined as an error. A quadratic (square) value function is constructed by taking the weighted sum of the squares of these errors. Subject to restrictions on future entries, entry levels, and moves, this value is chosen to minimize function. The optimization problem to be solved is a quadratic programming problem and an active set solution strategy is used. 'Aggressiveness'; It can be seen as returning the product to the target area determined by the slope of the built 'funnel' edge to bring it within the allowable range. Thus, this edge serves as a linear reference orbit, combining this concept with the funnel concept. Conventional setpoint control of a variable is achieved by making the low and high limits for that variable the same. Feedforward is handled similarly to combat the effects of measured disturbances. When the disturbances projected on the system outputs go out of the allowable range, they are driven back, again with a 'funnel' reference. Since there is usually no feedback in feedforward systems, systems can be more aggressive without the risk of being unstable. The RMPCT controller is organized in two stages, one for optimization and one for control [41].

3. MATERIAL AND METHODS

3.1 OPTIMIZATION ALGORITHMS OVERVIEW

Optimization is the process of obtaining the best possible process under certain conditions. The goal of every decision is to end or maximize utility. Effort is worthwhile, and a project to use it can be called a goal or a goal. Authority - The best or most restrictive type of authority. 67 The amazing process is the process of "becoming good" when we can take "myamilito imilito or mito or mito or nom" and change it. "Best" in increments of . means "maximum" or "minimum" depending on the context. "Excellent" is jargon for a stronger word than "best", convenient for everyday use. ||Important theory is the field of mathematics, including sampling, search, search, search, search, search, search, and many other disciplines. An application is a method, a method and a collection (expression) of a method, a method, an application and a sequence (comadikimanikimanikimanika). For example, Large Scale Diamond Optimization in Large Scale Forests [42]. Searching for customs in the search area saves energy and time. Its investigative methods can only be used to conduct as complete an investigation as possible. So the problem is solved. Each task is defined by the chosen solution (maximum search, etc.). This request must supplement it in order to achieve the desired result under certain conditions. Constraints. Optimum is a tool to find all the solutions. "Used best as a topic estimator to fundamentally optimize, or as a scoring mat or solution to optimize by the same criteria. When aiming for a goal, it learns that if it plans in this way, it can find all the possible solutions. The main concern of a problem is always meta-intuitive. It is done with a purpose In general, indeed, is our learning experience, as with most children, hard work [43]. and achievement. Metaheuristics were first developed in the mid-1980s as a new way to solve combinatorial optimization problems. Since the 1990s, with the discovery of new concepts and research methods, metaheuristics have become a powerful tool for solving common problems. Recently, metaheuristics have been shown to be used in practice to solve a large number of use cases. Many real problems today require fast and quality solutions. As a result, scientists and practitioners devise new methods knowing that they spend days or weeks solving these problems with accurate traditional methods [44]. Metaheuristic methods have been developed as an advanced problem solving strategy to bridge the gap between European and other search methods, including conventional search methods. These methods provide a general strategy for developing a set of methods that can efficiently and accurately find approximate solutions to algorithmic structures and search, optimization, and machine learning problems. . In metaheuristic algorithms, goal means "for" or "highest level". In general, these algorithms are better than simple heuristics. All heuristic algorithms use a compromise between local and global searches. Different solutions are often the result of random selection. Some researchers use the terms heuristics and metaheuristics interchangeably. Metaheuristics is an effective method of finding an acceptable solution to a complex problem through complex trial and error over a period of time. The goal of these methods is to find a stable solution within an acceptable period of time. Also, the term meteoritic is used for two completely different things. First, high-level frameworks are a set of interrelated concepts and strategies that provide insight into the development of optimization algorithms. Second, it refers to the specific application of structural algorithms or other combinations of structural concepts to solve specific optimization problems.

In addition, adaptive computing uses shared data to solve specific computing problems. The term "goal-intense" comes from the Greek word "heuriskein" which means "to find" or "find" and the word "intense" has meanings such as "beautiful", "adult", "mature", and goal. -intuition is synonymous with metaintuition. In many real-world programs, having more complex factors, parameters, and constraints that affect system behavior is fundamental science in many areas to ensure optimal use of resources. courses require a traditional approach to design thinking. On the other hand, the complexity of the problem of interest makes it impossible to find a solution or a combination of possible solutions. Therefore, the main task is to find and find the right solution to this problem. In this sense, the ambiguity and unpredictable behavior of more complex meta-heuristics can be very practical and problem-solving.

Most classical optimization heuristics derive optimal solutions from existing solutions based on field research and iterative methods. This navigation usually ends when the first local optimum is reached. However, the randomization and screening methods used to optimize these decisions are often inefficient. Metaheuristics combines large amounts of European data to provide a better solution than local search. The main components of the metaheuristic algorithm are focus/exploitation and diversification/exploration. Diversification, research to create different solutions. Knowing the chosen solution allows you to focus on each direction. I recommend it. Randomization helps you diversify your choices without being tied to one focus. The diversification step allows the algorithm to scan the search space more efficiently. On the one hand, these methods are based on various features of nature and specific abilities that a certain organism uses and uses during its life, various physical and chemical phenomena that become important targets, and various evolutionary, genetic and natural features. should be developed. All natural systems. For example, the memory of a forbidden person, the trap of the Pascal algorithm, the genetic structure of the genetic algorithm. Imitation of nature. These methods have many differences, including individual ones. For example, military intelligence techniques such as particle breeding optimization, cocoa hunting (CS), and fire algorithms describe the intelligence of predatory organisms called prey. These heuristics are better because they are simple and easy to understand.

3.1.1 Optimization History and Development

Optimization has a history as old as human existence in life. Humans, various animals and plants, fungi, bacteria, etc. All forms of life have the same housing, the same food, the same hunting and the same reproduction, but they must choose different alternatives to survive, and they want to make the best choice. This is an important issue to increase the chances of survival of organisms and ensure the continuity of life. The philosophies of Plato and Aristotle serve this specific purpose. Both focus on moral issues to improve individual and public behavior and optimize the functioning of the country to achieve the best possible human way of life. On the other hand, Pappus of Alexandria showed that the best solution for storing honey in a hexagonal honeycomb pattern was a cylindrical three-dimensional structure, which he called the honeycomb hypothesis. However, the development of methods for solving optimization problems dates back to the days of Newton, Lagrange and Cauchy. In this regard, thanks to the contributions of Newton and Reifnitz to mathematics (calculus), various differential calculus methods for optimization have been developed. Meanwhile, mathematician Leonhard Euler, along with Bernoulli, Lagrange, and Weirstrass, used differential equations to perform general solutions to many optimization problems and variational calculi related to function minimization [45]. In 1784, G. Monge was one of the first to consider the assignment problem, a kind of optimization problem, assuming that combinatorial (discrete) transportation problems, especially handling problems, are continuous . . In 1795, Carl Friedrich Gauss introduced the method of least squares, which essentially minimizes the sum of the squared errors of the estimated measurements for each data point. The most important application of this approach is data fitting. Also, for problems with other constraints, the optimization is Lagrangian first. Cauchy made the first application in 1847 using the top-down/top-down method to solve unlimited optimization problems. Another method for solving optimization problems is linear programming. In the late 1930s, an efficient method for solving linear programming problems, also known as linear programming, emerged. Against this background, in 1939, Kantorovich developed a solution to several production and transportation planning problems. Linear programming models were formulated as general optimization problems, and in 1947 GB Danzig described one of the most common scientific computational methods ever used to solve such programming problems, devised a simplex method which could be considered as one and developed linear programming. programming solution. In general, programming methods apply well to all combinatorial optimization problems. Phrases of mathematical programming often used as synonyms for optimization include studying the mathematical structure of optimization problems, discovering different methods of problem solving, studying the mathematical properties of those methods, and studying the computers. Appeared in the 1940s. Although neither method is suitable for solving nonlinear programming problems, Carroll, Fiacco, and McCormick were able to solve many difficult problems using the methods used in unconstrained optimization problems. On the other hand, Kuhn and Tucker's 1951 study of the conditions necessary to find an optimal solution to a programming problem laid the foundation for research that can be conducted using nonlinear programming. In 1952 Richard Bellman published the first research paper on dynamic programming. Dynamic programming is used as an optimization technique to reduce complex problems to simpler ones. In addition, the optimization principle for dynamic planning problems proposed by Bellman in 1957 led to the development of constraint optimization methods [46]. In the 1960s and 1970s, algorithms based on advanced mathematical structures were developed for some optimization problems such as linear, quadratic convex and nonlinear convex programming. In the 1980s, software packages that could be implemented using advanced IT frameworks and systems became popular to run these algorithms. In this context, the idea of iterative logic and system gain to solve the infinite horizon problem was proposed by Ron Howard in 1960. New programming methods were developed. Karmarkar suggested these approaches for complex real-world problems such as routing, scheduling, and scheduling. Today, more advanced optimization methods are used, especially for solving real-world problems, due to their non-linear nature and complexity. These methods are based on different algorithms called heuristics and swarm intelligence, origin of natural processes, etc. It is based on more complex metahorites that one of these methods, a method called simulated annealing, was introduced in 1953 by the American physicist Nicholas Metropolis as the first analytical method based on probability. In 1958, Friedberg made the first advances in genetic programming, in which learning algorithms were used to develop programs incrementally. In 1962, several researchers developed evolution-based machine learning and feature optimization algorithms. The first progress in this field of improvement was made in 1965, when German scientist Ingo Reichenberg developed a technique called evolutionary strategy. As two search parameters, it mainly uses mutation and selection with problem-dependent notation. In order to solve optimization problems in the future, genetic programming methods appeared, which is a token optimization technique for creating computer programs according to the principles of natural selection. With all these step-by-step developments, new advances in computational methods and computer systems have led to the current research of flower and bat pollination, artificial bird algorithms, and cuckoo clocks. Like many new metaphysical techniques [47].

3.1.2 Objective Function

Any optimization problem consists of the Objective function (also known as the "cost" or "payoff" function) and equality/inequality constraints. These limits are determined by the "physics" of the problem and can be derived from physical considerations. However, defining the objective function is the most important part of any optimization problem [48]. An objective function is the encoding of a problem objective as a mathematical function or computational model used to measure the quality of a given problem solution. Essentially, it is an interface between the algorithm and the real problem and plays an important role in routing without the algorithm, but the search space provided without the algorithm contains no indication of the performance of the solutions produced. For multi-objective problems, the problem can be defined as a minimization objective whose goals are to obtain low value solutions relative to the objective function, or as a maximization problem with higher value solutions.

3.1.3 Applicable Solutions and Impossible Solutions

Applicable Solutions and Impossible Solutions If any value is specified for the decision variables, it is called a solution. Viable solutions are those that meet the constraints on the problem parameters, especially the hard constraints, within the search space of the problem; In short, a solution in which all constraints are met is called a viable solution. On the contrary, a solution in which at least one constraint is violated is called impossible solutions[48].

3.1.4 Best Solution

The use of the term "best solution" implies that there must be more than one solution, all with different levels of value. What makes the most sense in terms of quality often depends on the actual problem, the method of resolution, and the tolerances allowed. Where the term "best" has an absolute definition, certain types of businesses have clear answers. In terms of optimization, "best" in these cases refers to the single global optimal problem. However, other topics may have different overall preferences.

3.1.5 Hard Constraints and Soft Constraints

Hard constraints on a problem are conditions that must be met for a solution to be viable. Also, soft constraints are constraints that we want to please but are not mandatory; therefore a solution that violates one or more soft constraints can still be considered viableA common way to handle soft constraints when finding solutions to an optimization problem is to penalize solutions when the soft constraint is not satisfied. The objective function of many questions is therefore the level of fines for soft restrictions. This means that the solutions that do not violate the soft boundary conditions are the best. In the language of operations research, hard constraints define a set of viable solutions, while soft constraints describe a function that needs to be tweaked to select one of the possible solutions. If both types of constraints are represented by items, the formula created by combining all the items may not be satisfactory. To find a solution to the original problem by the usual feasibility method, it is necessary to try to subtract several soft subsets of the problem from the representation of the problem until a satisfactory formula is found. Given the relative importance of soft constraints, such space exploration can be difficult and expensive to implement in practice, even when the theoretical complexity of the whole process is the same as traditional feasibility. We know, for example, that there are m students and k summer courses. Each student has potential teammates to develop the course with [49].

3.1.6 Batch and Continuous Optimization

Discrete optimization involves the optimization of problems characterized by a limited number of states accepted by the input parameters. In addition, continuous problems usually obtain solutions from an infinitely large solution set. These solution parameters are valid continuous members of the set. However, the set of possible solutions is small, but not infinite, because numerical methods do not provide the necessary accuracy for a "true" continuous solution. Practical optimization of both types of problems can be approached using similar methods (at least for imprecise heuristics), but there are considerations for efficient optimization of each type of problem. For example, a continuous optimization problem is more solvable than a discrete optimization problem because its inherent regularity allows us to use information about the objective and the constraints to solve the question about the behavior of the function at all points close to the point x of the function. On the other hand, the behavior of the objective function may differ between distance measurements and points considered close [50].

3.1.7 Problem Difficulty

Several reasons for solving real-world optimizations effectively are outlined in the following section:

a. The search space is too large to allow the use of a comprehensive search.

b. The problem is so complex that it requires using such simplified models of the problem domain to indicate any answer in any way, and thus any solution found is essentially useless.

c. The objective function is noisy or changes over time, thus requiring that entire series of solutions are required rather than a single solution.

d. Finding a viable solution to the problem is also difficult because the search space is very limited. The complexity of solving this problem using an algorithm is closely related to the complexity of the calculation. H is the amount of time and resources, like B. memory, that are needed for this. The complexity of the computation depends on the number of input parts needed to implement the method. This relation was proposed by Bachmann as a total constraint and generalized by Landau. Complexity examines how difficult it is to solve an optimization problem. The problems are classified according to the nature of the optimization algorithm. If the high-speed resolution is unknown, it is classified as "complex", otherwise as "simple". There are three important concepts of computational complexity.

e. The size of a particular task depends on the size of the task (number of parameters in the task). It depends on the size of the set of values that can define each parameter considered. This is more of an algorithm runtime than a problem. Execution time is the number of basic operations the algorithm needs before it can start solving a particular problem. The general understanding of computational complexity is that solving big problems takes time. However, this is not always the case. The best-known definition of the complexity of a problem is the relationship between the size of the problem being solved and the worst execution time of the algorithm used to solve it. It refers to the concept that one question can be transformed into another when viewed correctly. This is called problem reduction. Optimization problems have a different nature. A single-objective or multi-objective optimization problem can be limited, limited, or combined. This is discussed briefly in the next section [50].

f. One or more goals: An improvement issue based on a specific goal that you want to maximize or minimize is considered a single goal improvement. These themes can combine several objectives into one main objective. The goal of single-objective optimization methods is to find the optimal solution individually or the best combination of multiple objectives. On the other hand, many complex scientific and industrial optimization tasks are general in nature. These problems involve several conflicting standards or objectives that must be achieved simultaneously. Several basic optimization activities involve many conflicting goals that must be achieved within specific constraints. Constraints or no constraints: Most real-world optimization problems have constraints that are not violated in the search for an optimized solution. So this problem has an objective function f(x). This capacity can be reduced or increased within certain limits. On the other hand, unconstrained optimization problems are unconstrained, unconstrained and depend on real variables. These actions contain an objective function to decrease or increase the f-value. Joint optimization: Unlike multi-criteria optimization to find the optimal values of a given variable to maximize or minimize the objective function, many practical problems of maximizing or minimizing the objective function involve various mathematical techniques. Here, various combinations of unordered combinations of k-dimensional elements are considered, not the elements of an array.

g. In general, real-world problems are becoming more complex, and traditional mathematical programming methods are becoming increasingly difficult to solve and optimize. However, a satisfactory solution to the optimization problem can be found using metaheuristic algorithms. A metaheuristic is an algorithm designed to solve a variety of complex optimization problems without the need for deep adaptation to each problem. It is also used in the Greek "meta" to denote a high level of heuristics. Metaheuristic methods are widely used in industry and services to solve complex problems in many fields, from finance to production management and engineering. The next section describes the metaheuristic algorithm [51] in detail.

3.1.8 Discovery and Exploitation

Every search algorithm needs to address the discovery and use of a search domain. Exploration refers to the process of visiting completely new areas of a search area, while exploitation is the process of visiting these areas of a search area in the neighborhood of previously visited points. To be successful, a search algorithm must establish a good ratio between discovery and exploitation. From another perspective, exploration and exploitation explain global exploration and local search, respectively. Undoubtedly, this description reflects one aspect of its properties, but it is unreliable to distinguish between exploration and exploitation based solely on the scope of search, because there is no strict threshold to defend its local scale. A sure but pointless measure is to strictly restrict the search to keep it within the entire search area, and any search within a narrowed area will be considered exploitation. In machine learning algorithms, discovery and exploitation are related to the acquisition and use of knowledge, respectively[52].

3.1.9 Local and Global Search

Local metaheuristic search finds good solutions by making iterative changes to a single solution, called an existing solutionThese changes are called moves and are usually small, hence this class of metaheuristics. The set of solutions obtained by applying an activity to a given solution is called the neighbors of this solution. Depending on how the solution is expressed, different types of motion can be defined. Each type of traffic determines the structure of its own zone. A solution that is better than any surrounding solution is called the local optimum. However, global optimization finds the best solution to the optimization problem. If the current solution is a great locus, the metaheuristic EA uses strategies to avoid this great locus. It is this strategy that characterizes metaheuristics, from which the name metaheuristics often derives. Global search methods are more exploratory in nature (e.g., simulated annealing, genetic algorithms, and particle swarm optimization), while local search optimization algorithms are more exploitative and method hungry. random adaptive search and tend to search locally iteratively. There are many hybrid methods. It integrates the local search capabilities of the local search algorithm into mechanisms that improve population metaheuristics/global search [53].

3.1.10 Single vs. Population

Local and population metaheuristics, as well as the number of solutions governing local metaheuristic research, determine whether metaheurism is a local or population metaheuristic solution. First, we use a population path and algorithm to determine the metaheuristic of a given optimization problem. In general, algorithms based on hypothetical decision-making are more appropriate, but predictive population-based descriptive surveys are more exploratory in nature [54]. Orbital methods use one solution at a time and start with the first solution. During iteration, these algorithms create paths in the search space. Here it is assumed that solution may or may not be close to the current solution. In a population-based algorithm, you first create a set of multiple solutions, and then on each iteration, you change the set of solutions to find the optimal solution in the search space. These algorithms re-standardize or modify various solutions depending on the strategy adopted to explore and exploit the search space [55]. Our algorithms allow us to not look at the starting point and wander around to improve the solution. However, cluster-based algorithms can perform multi-stage searches in parallel. Population-based algorithms have the advantage of providing an efficient search space for searching. This method is suitable for global research. Because global research and regional development are possible.

3.2 DIFFERENTIAL EVOLUTION ALGORITHM

The Differential Evolution Algorithm (DE) is a population-based algorithm proposed by Price and Storn in 1995 [56]. The algorithm is simple but powerful, and it is a very successful algorithm especially in solving continuous optimization problems. It is based on Genetic Algorithm (GA). However, unlike the classical GA, the variables are represented by their real values. Although real-valued variables can be used in GA from time to time, the main difference is a number of changes made in the use of genetic operators. Crossover, mutation, and selection operators are also used in DE. However, unlike GA, each operator is not applied sequentially to each individual in the population. In DE, individuals are handled one by one, and a new individual is obtained with the help of randomly selected individuals (mutation and crossover operation). Then, the existing individual is compared with the new individual and the better fit individual is included in the population (selection process). Mutation used in DE is an important operation that improves algorithm performance and makes it more robust. Again, the algorithm is fast, simple, easy to use, can be changed and can be coded, has high global search capability, low computational cost, allows integer, discrete and mixed parameter optimization, etc. It is often preferred because of its characteristics.

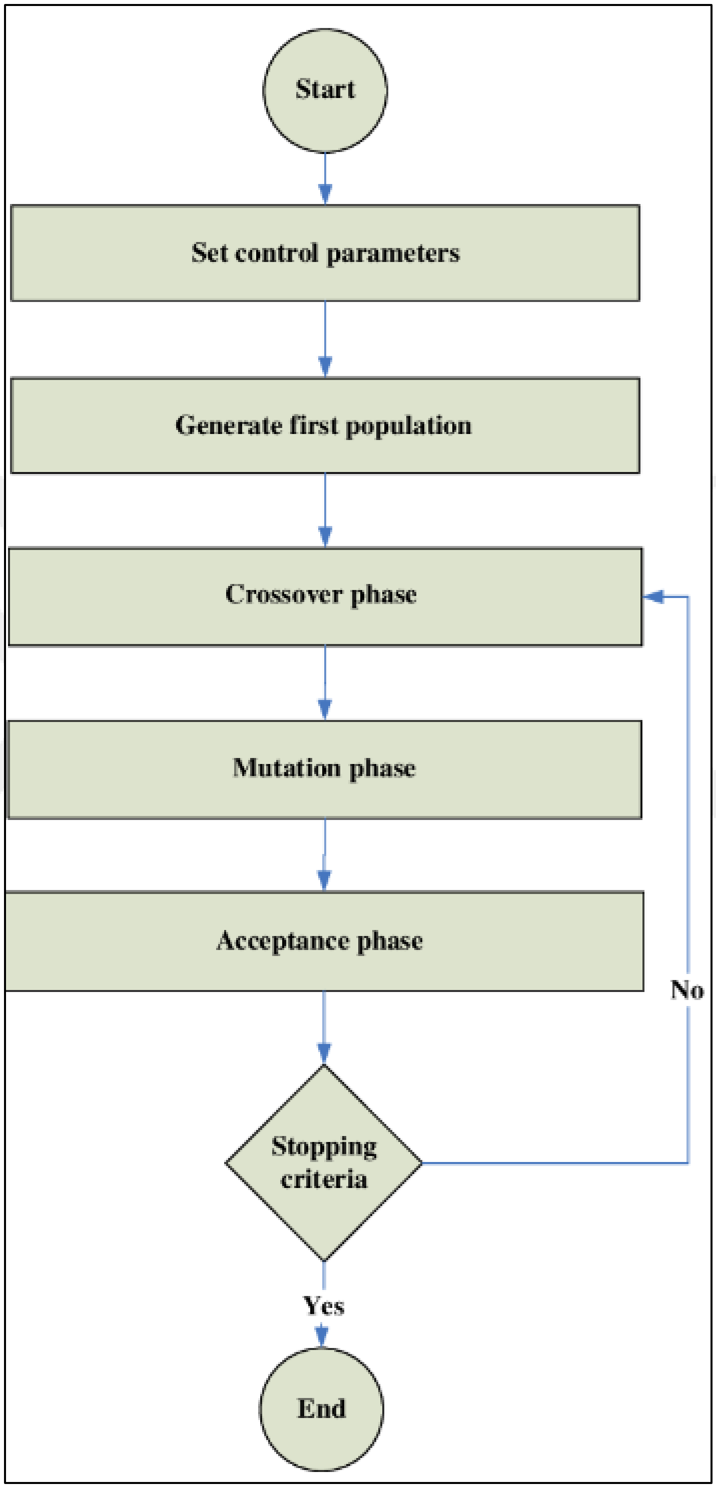

Figure 3.1: Differential Evolution Algorithm flowchart

3.3 ARTIFICIAL BEE COLONY ALGORITHM

Artificial Bee Colony Algorithm (ABC) is an optimization algorithm based on swarm intelligence proposed by Karaboğa in 2005 [57]. In the algorithm created by modeling the foraging behavior of bees, there are three types of bees: attendant (worker), explorer and onlooker. The following assumptions have been made in the algorithm.

a. Each food source is used by only one employed bee.

b. In the algorithm, there are attendant bees as much as the number of food sources.

c. The number of employed bees is equal to the number of onlooker bees.

d. The employed bee of the depleted food source turns into a scout bee.

e. The location of the nutrient source determines the possible solution to the optimization problem, and the nectar amount of the source determines the quality (suitability) of the solution.

The basic operation of the ABC algorithm is as follows: At the beginning of the foraging process, scout bees look for a random food source in the environment. After the food sources are found, the scout bees become the attendant bees of the source they find. The employed bees start to carry nectar from their source to the hive. After emptying the hive with nectar, the attendant bees either return to the source or dance in the dance area to convey information about the source to the onlooker bees. Onlooker bees, receiving information about the source through this dance, choose a food source with a certain probability and start to store nectar by turning to this source. When a resource is depleted, the employed bee of that resource turns into a scout bee. The scout bee continues to store nectar by finding a random food source. This process is repeated until the termination criterion is met

3.4 PARTICLE SWARM OPTIMIZATION ALGORITHM (PSO)

Genetic Algorithm The genetic algorithm, which has the oldest history and has found the most application area, is based on a philosophy such as the survival of the best or the strongest/the strong defeat the weak, as in real genetics. Developed by J. Holland and named genetic algorithm (GA), this method is organized according to five biological processes called mating, reproduction, cloning/reproduction, crossover and mutation, which was created by being inspired by biological systems that can adapt to the environment and turn into highly successful organisms over generations. It is an algorithm developed for compound optimization problem [62]. The functioning of the algorithm is as follows:

a. The design code to test the population is determined.

b. The solution is started with an initial population for the identified problem.

c. The strongest individuals are selected from the initial population and the next new population is produced from these individuals by crossover, mutation and selection processes. In this way, the initial population becomes the parent population.

d. Using the main design values, the code of the new population is decoded and step 3 is repeated by evaluating the fitness (strength) of each individual in the population.

e. Search for new generations is continued until a certain number of generations is reached or the average amount of change in the fitness value falls below the specified tolerance. In this way, the best individuals are tried to be obtained from generation to generation. The specified fitness function provides a decision as to whether each population will contribute to the next generation populations to be produced. During selection from the population, although the probability of elimination is very low for the strongest individuals in the society, there is a possibility that even the best individuals will be eliminated. The advantage of this scheme is that although its overall fitness is low, it can save some individuals, including components that can contribute to a stronger solution. The diagram explaining the operation of these processes can be seen in Figure.

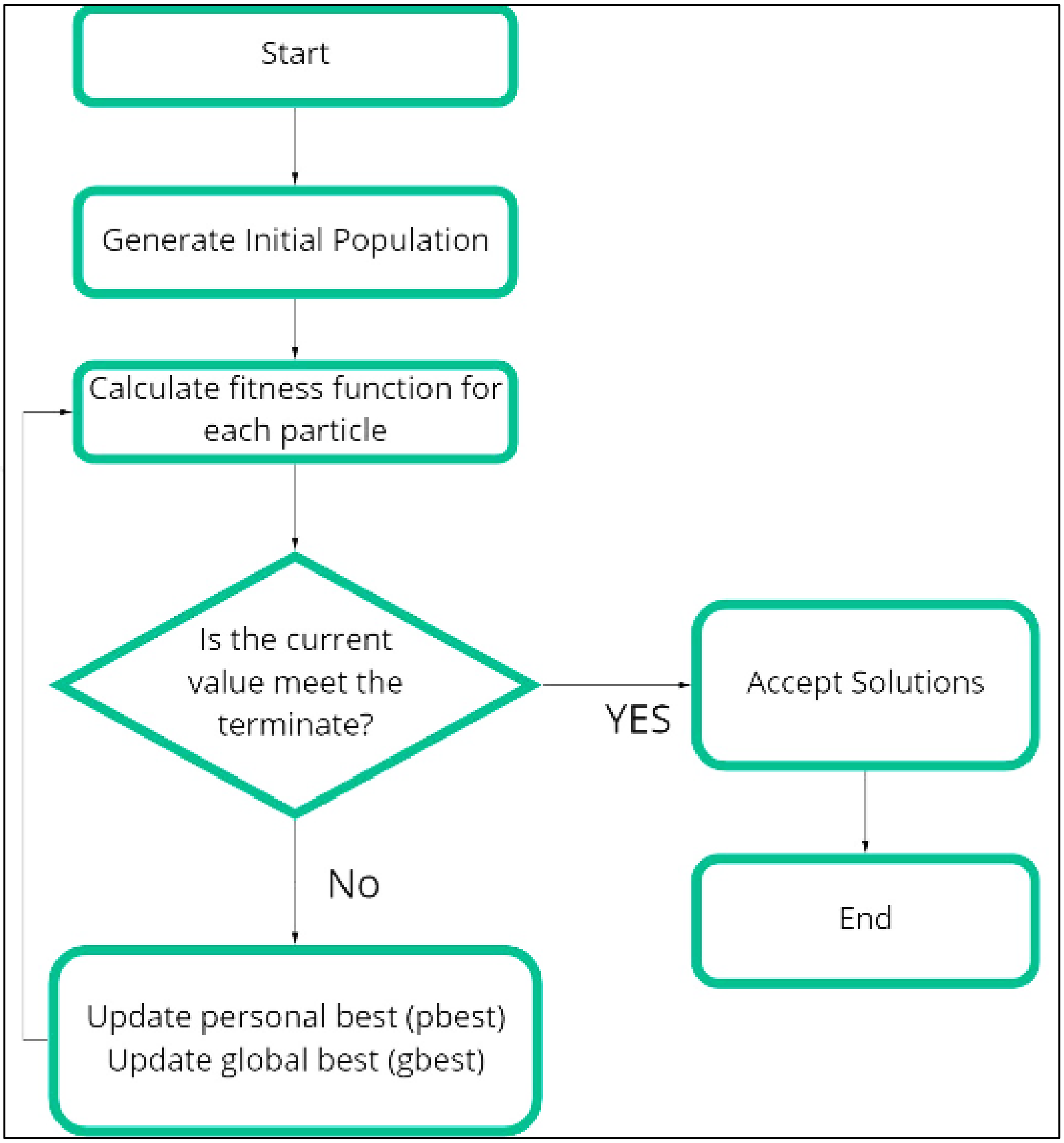

Figure 3.2: PSO flowchart

3.5 HARMONY SEARCH ALGORITHM

While musicians present any musical work to the audience, their aim is to realize it in the best possible way. For this purpose, they are constantly working to bring together the notes that best reflect their works and that are most pleasing to the ear. This process, which is necessary for the creation of a beautiful and effective musical work, continues until it is appreciated. Inspired by this process, Geem et al. In 2001, they developed an algorithm based on natural (improvised) music performance, which is known as the harmony search (HS) method and the aim is to search for the more popular harmony [58]. The operating logic of this developed algorithm is shaped not only by the best notes of a musical piece and presenting it to the appreciation, but also by the improvisation performance of a musician and the idea of performing it in the best way. From this point of view, there are three possible activities a musician can do during his improvisation performance, can play any famous piece of music entirely from his own memory. ii. It might play something similar to a known artifact. iii. It can compose new or random notes. Figure 3.3: General flow chart of genetic algorithms. 18 It can be said that these three options correspond to three different alternative situations in determining the harmonies to be selected in the optimization process with HS: harmony memory usage, pitch (tone) tuning and randomization. In the HS method with memory usage feature, the use of memory is an important concept, as it is similar to the selection of the most suitable individuals in the genetic algorithm, and the acquisition of the best harmonies to be transferred to the new harmony memory. The harmony memory evaluation rate, which is taken into account in memory usage, has a value between 0-1. The fact that this ratio is too high causes almost all harmonies in the harmony memory to be used and therefore the harmonies to be selected in the next iteration cannot be explored well.

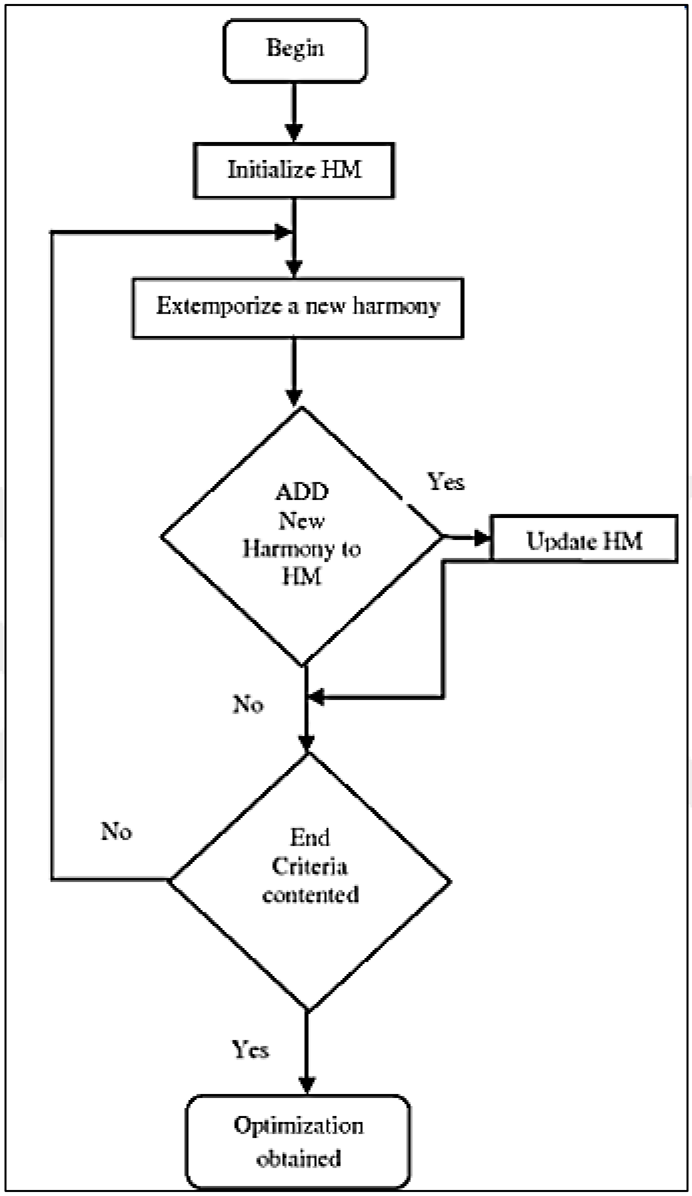

Figure 3.3: Harmony search flowchart

3.6 LEARNING BASED OPTIMIZATION

Rao et al. in 2011 proposed a meta-heuristic algorithm generated based on classroom teaching-learning processes and called it the Teaching-Learning Optimization (TLBO) method. The algorithm takes into account the influence of the teacher and the interaction with the students through an iterative process in order to improve the knowledge of the students and the class as a whole. But in practice, the teacher can move the average class to a certain level depending on the class's abilities. This change depends on several factors, but it is a random process. In this regard, the teacher, who is the most experienced teacher in the subject, should raise the level of knowledge of the whole class according to the skill of the teacher. Indeed, it influences the behavior of students to achieve certain goals [59]. Looking at this process, the learning-learning process depends on two factors, and according to this situation in the TLBO algorithm, the optimization process can be divided into two stages: teacher and student. The teacher phase aims to monitor the knowledge and learning skills of the teacher and their impact on student performance. The learning phase is the process in which students see how their personal efforts, such as knowledge sharing, collaboration, and interaction, affect their grades. In addition to teachers' influence on students, students can improve their knowledge in several ways, including through research and communication.

3.7 TABU SEARCH ALGORITHM

Tabu search algorithm is a method developed based on human memory and its ability to save memory. Tabu search (TS) was proposed by Glover in 1986 and the components of the algorithm include representative solutions, creation of the first solution, neighborhood (environment) structure, tabu list, tabu usage (duration), aspiration3 criteria, condensation, diversification and termination criteria [60]. One of the important features of this algorithm is the memory function, which can constrain some search directions for a more detailed local search, and makes it easier to terminate the local optimal solution search by remembering the non-optimal solutions determined before during the iterations without including them in the re-searching process. During iterations hafıza ile toplanan bilgileri kullanması sayesinde arama işlemi daha verimli hale getirilmiş olur.

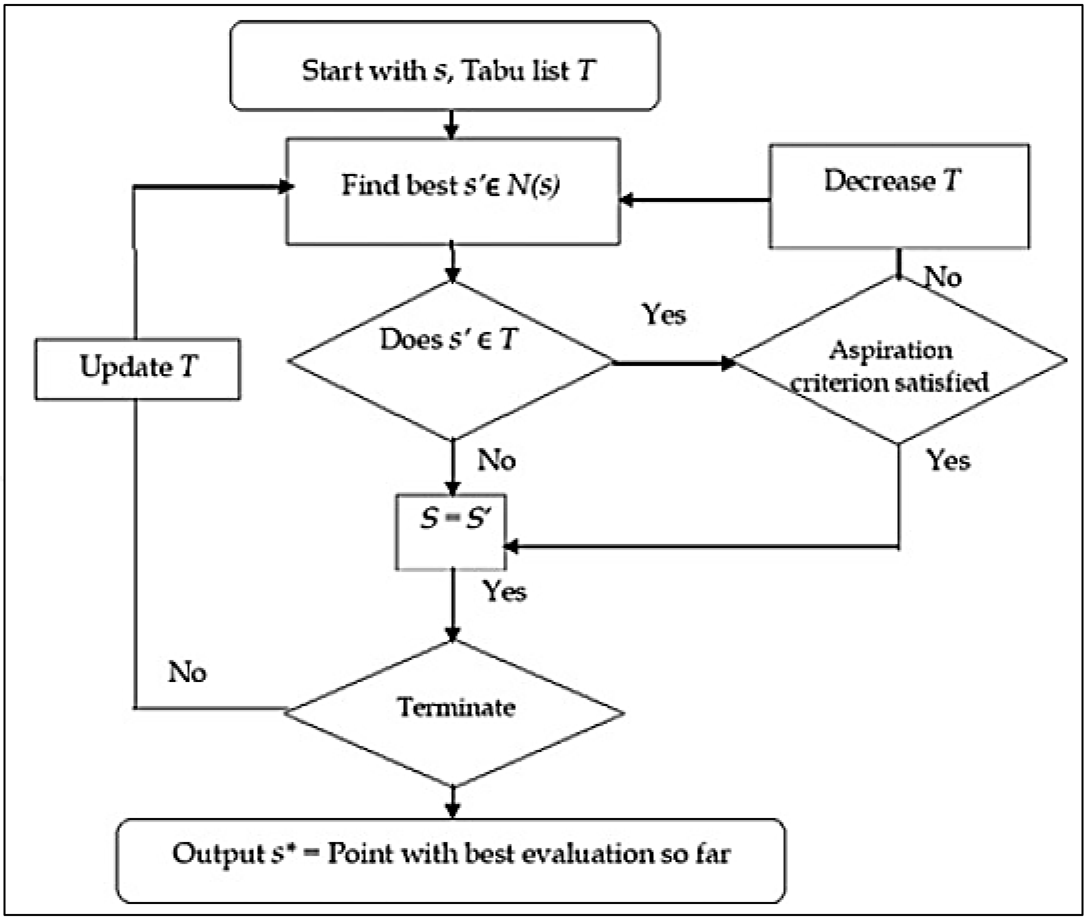

Figure 3.4: Tabu search algorithm flowchart

3.8 ANT COLONY ALGORITHM

The ant colony algorithm, which is one of the algorithm types inspired by various living species and their lives in nature, has been developed with inspiration from the real life and communication behaviors of ants and is expressed with the abbreviation ACO. ACO is the method whose first member is called the Ant System and was originally proposed by Dorigo in 1982. The same principle was proposed by Colorni, Dorigo and Maniezzo in 1992 for the solution of optimization problems, and it is a type of metaheuristic algorithm known as a collaborative research technique that mimics the aggregation behavior of real-life ant colonies [61]. Ants, which are social insects, live in colonies and give more importance to ensuring the integrity of the colony and the survival of the colony rather than being individual. In this respect, ants living in colonies act together and can communicate with each other while searching for food. One of the important and interesting features of ant colonies is their ability to find the most suitable (short) paths between their food sources and their nests. While walking from the food sources to the nest or from the nest to the food source, ants secrete a liquid called pheromone from their abdomen and in this way, they store it where they pass by creating a pheromone trail. Thanks to this liquid, ants are able to communicate with other ants and indirectly find the shortest path to a food source through this communication. As seen in Figure 3.5, the shorter one of the alternative routes between the colony and the food will accumulate more pheromones than the other routes after a certain period of time. The ability of ants to detect the scent of the pheromone causes them to choose routes marked with strong pheromone concentrations when choosing routes to traverse, and thus the entire colony begins to transport food using the shortest path. In this way, ants are allowed to return to the food source (or nest) thanks to the pheromone trail. Also, other ants can use this track to locate food sources found by other 21 nestmates.

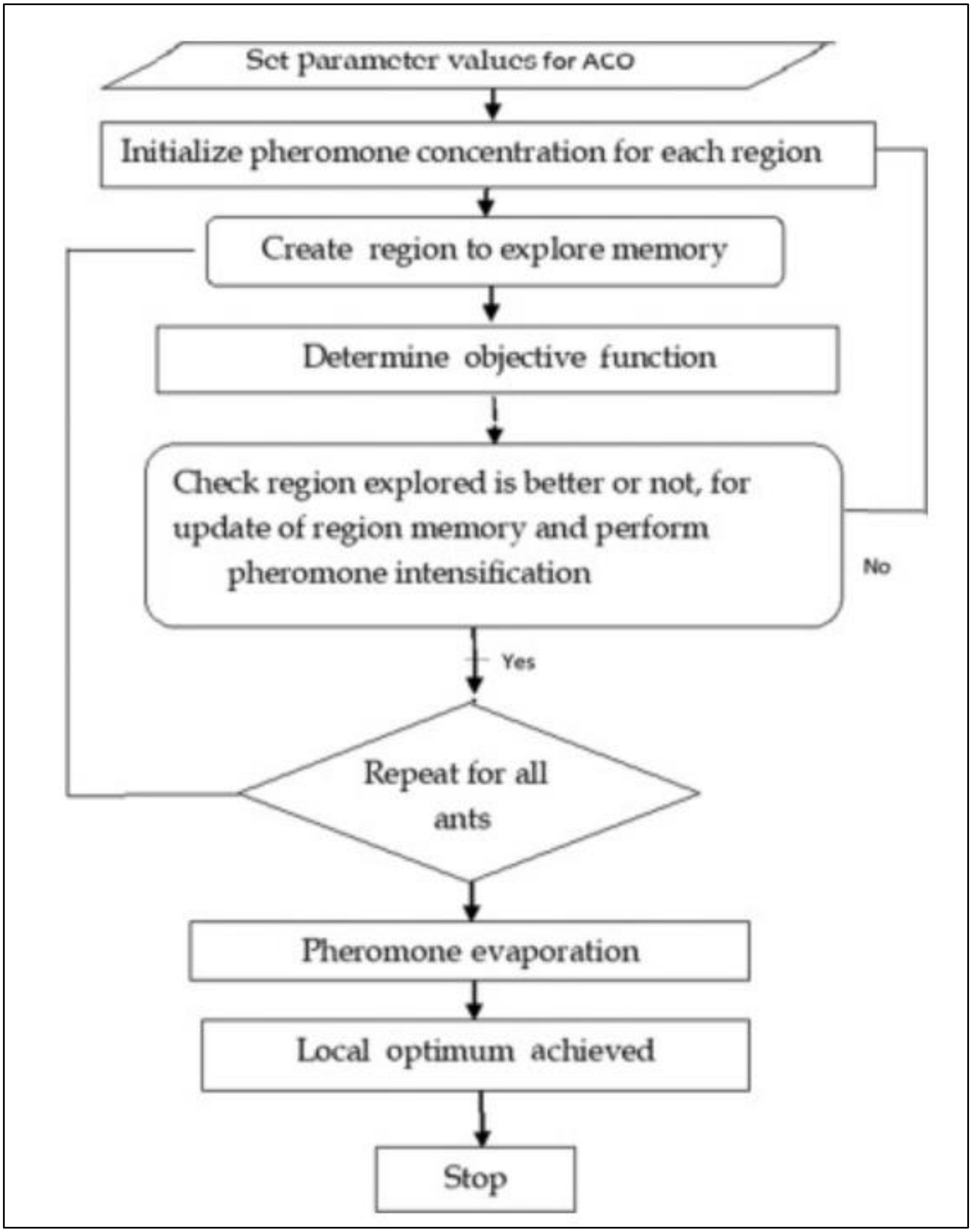

Figure 3.5: Ant colony algorithm flowchart

3.9 SIMULATED ANNEALING

In metallurgy and materials sciences, the process based on changing the physical properties of a certain solid material, such as hardness or strength, by heat treatment is known as annealing. Metropolis et al. Monte Carlo simulation algorithm was developed in 1953, which successfully models the physical annealing process. The emergence and name of the simulated annealing (SA) algorithm derives from its similarity to the Monte Carlo simulation model, which is quite successful in physical annealing to find low energy states of a solid. Figure 3.6: Foraging behavior of ants [67]. Nest Nest Nest Food Food Food A C B 22 In the operation of this algorithm developed by Kirkpatrick et al. in 1983, firstly, the melting process is performed in order to optimize the system at a high effective temperature. The temperature is then slowly lowered until the system freezes and no more changes occur. At each temperature, the simulation should take long enough for the system to reach a steady state. The number of rearrangements of temperature variables to reach equilibrium at each temperature value can be considered as an annealing process.

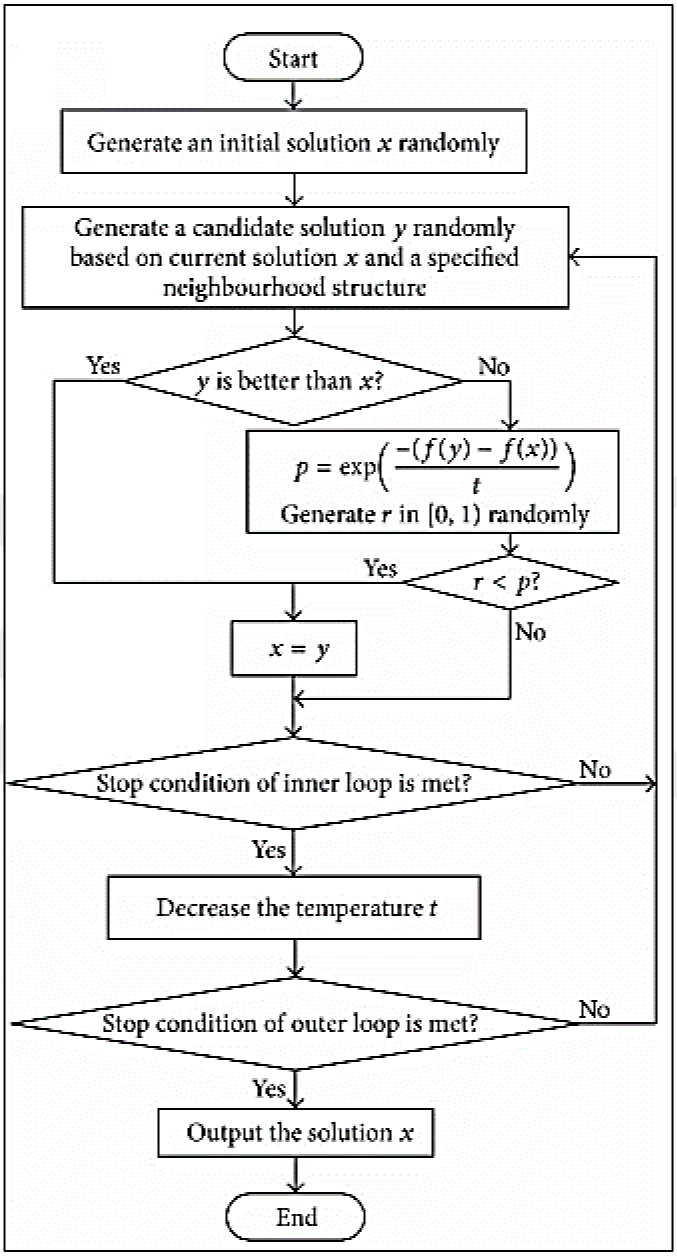

Figure 3.6: simulated annealing Flowchart

3.10 PROPOSED SYNCHRONOUS GENERATOR SYSTEM

In this section, new method-based LSTM which is one of best neural network types applied to synchronous generator system values. This study presented from number of steps to estimate the values of synchronous generator system as folows:

a. Start
b. Read features that obtained from UCI, the obtained dataset represented the problem well and used in several well known studies.
c. In the second step, the data preprocessed and used as input to the neural network model to perform the estimation issue.
d. The dataset devided into two sections train and test. The train set used for training the model to learin the features of the model. On the other hand the test data used to test the performance of the model. The test and train are important issues in building effective model.
e. In the training section the model used the train data to learn weight and basis that presented best results.
f. After the training complete the test section start to test the performance of the model. The testing the model led to evaluate the performance of the model to be ready to use in the real live applications.
g. Complete the execution

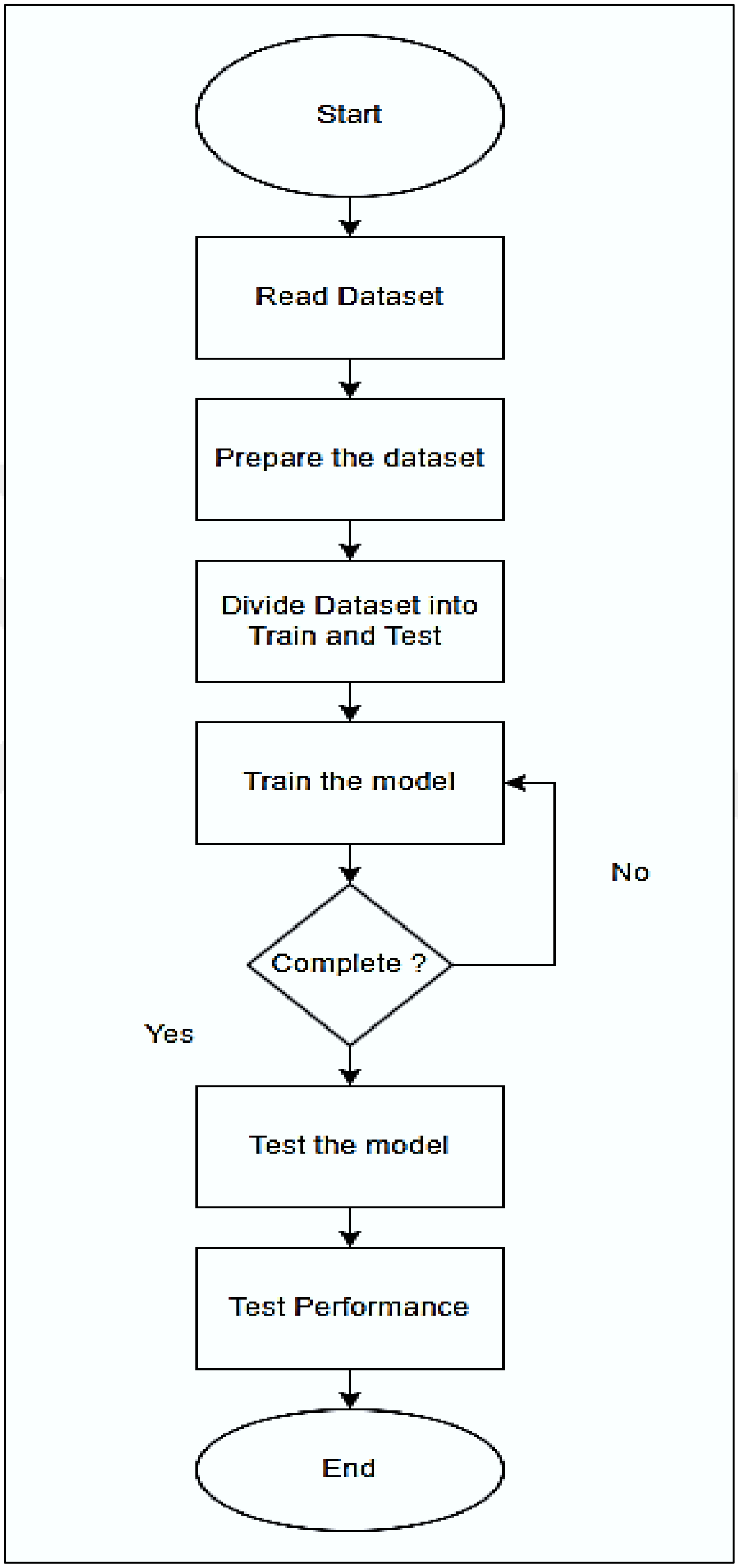

Figure 3.7: Proposed Synchronous Generator System Flowchart

4. EXPERIMENTS AND DISSCUSION

In this section, firstly the findings under the headings reflecting the aims of the research and then the interpretations in which the findings are tried to be interpreted as a whole are included.

4.1 SUPPORT VECTOR REGRESION (SVR)

A support vector regresion creates a hyperplane in a super- or infinite-dimensional space-domain that can be used for different tasks such as grouping, retrospective, or detection of inappropriate values . The real difference is that the higher the cutoff, the lower the overall error rate because the hyperplane is far away from the location of the training data, which is better for random set training. To simplify calculations, SVR diagrams can be used to define input bus information for the main activity and plan assignments to simplify calculations with real field variables. SVR algorithms are often used for prediction in life science applications. Permutations based on SVM weights have been proposed as a way to describe the SVR model. The results of the SVR preseted in the Table 4.1.

Table 4.1: Statistical Parameters of SVM

Parameter	Values
Mean error	0.564
Mean Percentage Error	0.896
Mean Squared Error	0.452
Accuracy	94.28

4.2 DECISION TREE (DT)

Decision tree model is a descriptive and predictive method in tree view. Depending on the amount of data, the efficiency of the algorithm, and the available memory, a decision tree algorithm can be constructed using sequential or parallel operations. A sequence tree algorithm is a type of logical model in binary tree format that is generated using a set of training data. It is used in research to estimate the value of an objective variable using independent variables [26]. It consists of a set of progressively organized rules. There are decision tree algorithms used to build entropy decision trees, CHAID, CART, ID3, and C4.5. The most commonly used algorithm in decision trees is cross-entropy. Entropy is defined as a measure of the disorder and randomness of a system. Entropy is a measure of the uncertainty in the data.

i. CHAID(Frame-Automatic-Interaction-Detection): It is a decision tree learning algorithm required to process only low quality data. It is a complement to the automatic interaction detector and theta automatic interaction detector procedures [27].

ii. CART (Classification – Regression trees): It is the most popular algorithm applied in the field of statistics. It helps decision trees gain credibility and acceptance to make binary splits on the data to achieve the goal in statistical fields [27].

iii. ID3 (Repeating binary structure algorithm): It is one of the algorithms developed by Quinlan to perform separation operations with the support of decision trees. The ID3 algorithm deals with classified data. Decision trees segment multidimensional data according to a certain feature. In each transaction, it is decided how to act according to the characteristics of the data. In order to create decision trees with minimum nodes and extensions, separation is done using other algorithms [28].

iv. The C 4.5 Decision Tree is the first source-controlled machine learning classification algorithm that has been implemented in a contextual way and is uniquely highly predictive.

Table 4.2: Statistical Parameters of DT

Parameter	**Values**
Mean error	0.497
Mean Percentage Error	0.735
Mean Squared Error	0.573
Accuracy	97.07

4.3 RANDOM FOREST (RF)

Random Forest is a classification algorithm that consists of many decision trees and extracts the class that is the mode (chosen by the majority tree) of the classes produced by the individual trees. The number of trees used in this way depends on the algorithm and data set used. Randomly selects another tree from the training data. The randomization method chosen depends on the algorithm. In general, the performance of other decision trees is improved. Using a random selection function to isolate each node has a higher error rate than Adabost. Unlike other decision trees with high or high distortion, this one uses averaging to create a natural balance between the two extremes. Random Forest is a meta-estimator that applies a set of classical decision trees to different subsamples of the data set and uses the mean to improve prediction accuracy and control overfitting. Each decision tree used in this procedure is generated using a random subset of the training data.

Table 4.3: Statistical Parameters of RF

Parameter	Values
Mean error	0.785
Mean Percentage Error	0.945
Mean Squared Error	0.856
Accuracy	93.56

4.4 ADABOOST

AdaBoost, short for Adaptive Boosting, is the first practical boosting algorithm proposed by Freund and Schapire in 1996. It focuses on classification problems and aims to turn weak classifiers into strong classifiers. This procedure first assigns a simple classifier to the data, correctly classified samples receive lower weights in the next iteration, and misclassified samples receive higher weights. Recalculate the weights for the next iteration and repeat the same method. After the iterations are completed, the calculated weights (automatically calculated weights for each classifier based on the error rate at each iteration) are combined to find a strong classifier that predicts the class with high accuracy.

Table 4.4: Statistical Parameters of AdaBoost

Parameter	Values
Mean error	0.956
Mean Percentage Error	0.685
Mean Squared Error	0.574
Accuracy	91.56

5. CONCLUSION

The extent of this study is to examine the possible enhancements that can be done using LSTM analytic control methods for the layout of power system stabilizer. It has been an important factor in the modeling of advanced control methods because of the inadequacy of the classical control methods in the dead time elimination problem in the systems and the difficulty of adding the constraints to the system in the controller design. Model Predictive Control, which is one of the advanced control methods, was examined within the scope of this thesis, and speed control of a direct current motor and a few other examples were examined comparatively. State feedback predictive control technique was used in the design.

LSTMs offer us with a larger variety of factors such as learning rates, and input and output biases. Thus, no want for fine changes. The difficulty to inform each mass is decreased to O(1) with LSTMs, comparable to that of Back Propagation Through Time (BPTT), which is an advantage.

Neural Networks is a extremely potent method and is employed for image classification and many other functions. One of the limitations is that, there is no memory linked with the model. Which is a question for subsequent data, as text or time sequence.

Consequently, LSTM is good means for something that has a sequence. Later the sense of a phrase differs on the singles that led it. This lined the way for NLP and story study to leveraging Neural Networks.

On the other hand, the LSTM have several disadvantages when we trained it in classical trained methods. These disadvantages presented below:

a. LSTMs need longer time to train
b. Its need additional memory to train
c. Its are simple to overfiting
d. Dropout is considerably tougher to execute in LSTMs
e. Its are receptive to various random weight commencements

Then, in this study we trained LSTM with PSO which led to avoiding these training disadvantages wgich is one of the most problems occurred in LSTM. The PSO used to find best weight and basis of the LSTM.

In future we advise the researchers to apply other optimization algorithms as routing protocols to present best performance in this filed. Furthermrore, we advise using genetic algorithms combined with other optimization algorithms presented in the fild of optimization.

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