OPTIMIZATION OF ELECTRICAL WIRING DESIGN IN BUILDINGS USING PARTICLE SWARM OPTIMIZATION AND GENETIC ALGORITHM

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**FACULTY OF ENGINEERING
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ABSTRACT

In Malaysia, the number of population in the cities is increasing due to urbanization and job opportunities. As a result, the number of high rise building is also increasing. Hence, electrical system is becoming crucial in the construction of high rise building so that the building could be occupied safely and comfortably by tenants or residences. Commonly, electrical system is designed based on the customers' requirements and it must comply according to certain requirements and regulation from authorities or standard bodies. The electrical wiring system design includes sizing of cables and bus ducts, customers' load and placement of load, cables and bus ducts. Therefore, these parameters have to be emphasized on the planning stage. In this project, the main objective is to optimize the electrical distribution system design in buildings using optimization methods, which are Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). The main reasons of using these optimization methods is to propose a minimum total cost and lowest voltage drop of electrical system design in buildings.Comparison between the optimisation methods and without using optimisation methods show that the total cost and total voltage drop are lower when using optimisation methods. Comparison between the results using PSO and GA shows that both methods yield the same total cost and total voltage drop but GA yields consistent results compared to PSO. Therefore, GA is more suitable than PSO in finding the lowest total voltage drop and total cost when designing an electrical system in a building.

ABSTRAK

Di Malaysia, jumlah penduduk di bandar-bandar semakin meningkat disebabkan oleh urbanisasi dan peluang pekerjaan. Hasilnya, bilangan bangunan bertingkat tinggi juga semakin meningkat. Oleh itu, sistem elektrik menjadi penting dalam pembinaan bangunan bertingkat tinggi supaya bangunan itu dapat diduduki dengan selamat dan selesa oleh penyewa atau kediaman. Kebiasaanya, system elektrik direka berdasarkan keperluan pelanggan dan mesti mematuhi keperluan dan peraturan tertentu daripada pihak berkuasa atau badan standard. Reka bentuk sistem pendawaian elektrik termasuk saiz kabel dan saluran bas, beban pelanggan dan penempatan beban, kabel dan saluran bas. Oleh itu, parameter ini perlu ditekankan pada peringkat perancangan. Dalam projek ini, objektif utama adalah untuk mengoptimumkan reka bentuk sistem pengagihan elektrik di bangunan menggunakan kaedah pengoptimuman, iaitu Pengoptimunan Kawanan Zarah dan Algoritma Genetik. Sebab utama menggunakan kaedah pengoptimuman ini adalah untuk mencadangkan jumlah kos minimum dan kejatuhan voltan terendah reka bentuk system elektrik di bangunan. Perbandingan antara kaedah pengoptimuman dan tanpa kaedah pengoptimuman menunjukkan bahawa jumlah kos dan jumlah voltan lebih rendah apabila menggunakan kaedah pengoptimuman. Perbandingan keputusan antara PSO dan GA menunjukkan bahawa kedua-dua kaedah menghasilkan jumlah kos yang sama dan penurunan voltan keseluruhan tetapi GA menghasilkan keputusan yang konsisten berbanding PSO. Oleh itu, GA lebih sesuai daripada PSO dalam mencari jumlah penurunan voltan terendah dan jumlah kos apabila merancang system elektrik di bangunan.

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LIST OF SYMBOLS AND ABBREVIATIONS

PSO	:	Particle Swarm Optimization
GA	:	Genetic Algorithm
XLPE	:	Cross-Linked Polyethylene
BBT	:	Busbar Trunking System
ACB	:	Air Circuit Breaker
C	:	Celcius
mV/A/m	:	Mili-Volt per Ampere per meter
I_{load}	:	Load Current
A	:	Carrying Capacity
ACB	:	Air Circuit Breaker
I_{cb}	:	Current Breaker
V_d	:	Voltage drop
IEC	:	International Electrotechnical Commission
TOC	:	Total Owning Cost
PVC	:	Polyvinyl Chloride
LV	:	Low Voltage

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CHAPTER 1: INTRODUCTON

1.1 Project Background

In the construction of high rise buildings today, electrical wiring design is one of the important aspects in ensuring that building could be occupied by tenants, for example condominiums and offices. However, it must meet certain requirements from clients, authorities or standard official bodies and follow certain procedures during design stage. The most important aspect for this project is to control the voltage drop as long as it complies with IEC standard and financial budget from client with minimum costing.

In this research project, cable and bus duct are two common components used to distribute low voltage (LV) electrical power from a main switch room to houses or offices for each end user. First and foremost, cable sizing is important to function endlessly under full load conditions without being damaged. Moreover, it is necessary to hold up the worst short circuit current flow and ensure that the protective devices are effective during an earth fault. Also, the supply to the load must be with a suitable voltage and avoid excessive voltage drops [1].

Electrical installation in high rise building becomes important and it is necessary to use modern electrical installation methods. The coordination of arrangement of the cables and bus ducts in the riser must be provided. In an electrical distribution system, one area where savings can be made and provide the features listed above is with the use of busbar trunking systems [2].

Voltage drop calculation is the main factor in the LV distribution system. It can be calculated from the outgoing of the main switchboard to each final distribution board at the offices or houses. The factor supporting the voltage drop is the length of cables or bus ducts and the total load current is obtained. Voltage limits seen by consumers become one of the determining factors in system component design. It is normal to allocate a permissible voltage drop through each system component, which becomes a limit of magnitude of the load flow [3]. Clause 311 of MS IEC 60364 Part 1 states that the maximum demand for each circuit is determined while ensuring an economic and reliable design within the permitted voltage drop limits [4].

At a client side, budgetary and costing are always important and have to be taken into consideration during the planning and designing the low voltage electrical system. As a result, marginal cost is always emphasized by the client. Marginal cost is an estimation of how economic cost would change if output changes [5].

The most crucial part is to obtain low voltage electrical design with low cost. Generally, there are several methods to calculate the voltage and the cost for electrical design. In this project, parameters such as the number of cables and number of bus duct is tuned by means of conventional method, particle swarm optimisation (PSO) and genetic algorithm (GA). Comparisons of the results between these methods are made.

1.2 Problem Statement

Growing population and industrialization have led to the rapid growth of high-rise buildings. Electrical wiring design is an important aspect to be considered for the construction of high rise buildings. Proper electrical wiring designs in buildings are very important in order to ensure electrical power can be supplied to the building continuously and without problems. A major consideration in electrical wiring design in buildings must meet certain requirements and follow certain procedures during design stage. Budgetary from client shall also be considered to ensure that design can be implemented to the site. Sometimes, marginal cost is important as an initial value engineering, which means that the system distribution designed is not over-designed and can be delivered to end user safely. However, to design electrical wiring system while maintaining low voltage drop with a lower cost is a challenging task. Therefore, electrical wiring design using combination of cable and bus duct with lower cost is proposed in this work using optimisation methods, particle swarm optimisation (PSO) and genetic algorithm (GA).

1.3 Objectives

The objectives of this project are as follows:

1. To design electrical wiring in buildings based on the customers' requirements.
2. To propose electrical wiring design in buildings with minimum cost and lowest voltage drop using particle swarm optimisation and genetic algorithm.
3. To compare the performance of particle swarm optimisation and genetic algorithm method for electrical wiring design in buildings.

1.4 Scope

The limitations of this project are:

1. Design low voltage drop and low cost electrical system for distribution using two different materials, which are cables and bus duct.

2. The parameters optimized are the number of cable, number of bus, cable model and bus model by using particle swarm optimisation and genetic algorithm method.

1.5 Research Report Outline

This thesis is organized into five chapters. Chapter 1 provides an overview of the project that includes project background, problem statements, objectives and scope of the project.

Chapter 2 reviews previous literature, including the causes, effects and solutions regarding to electrical distribution system design. The conventional method, particle swarm optimisation and genetic algorithm are explained.

Chapter 3 describes the details of the proposed electrical low voltage distribution system for buildings. The suggested method and test system used are also explained.

Chapter 4 explains the result of the optimization by using Particle Swarm Optimization and Genetic Algorithm methods. The results obtained were analysed and the performance of the methods was compared.

Finally, Chapter 5 draws the conclusions of this work and recommendations for future works to enhance the accuracy of the methods used in this work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter discusses previous works related on electrical wiring design system in buildings on how to optimize the voltage drop and cost. The optimization of electrical wiring design in building using particle swarm optimization and genetic algorithm is also discussed in this chapter.

2.2 Distribution System

For all building constructions or remodelling building projects, clients must first have a concept for the design before a designer can produce a set of building plans. These plans convey all the required information to the local inspection authority and associated building trades so that the construction or remodelling can take place. Since commercial and industrial buildings consist of a various number of electrical design system, these plans include specific electrical designs and additional documentation to verify that the design conforms to all required building codes [6].

The function of the electrical power distribution system in building is to receive power at one or more supply points and deliver it to final circuit, such as lighting and switch socket outlets. The importance of the distribution system to the function of a building makes it imperative that the best system can be designed and installed as shown in Figure 2.1. The best distribution system is one that is cost effective and high safety and supplies adequate electric service to both present and future probable loads. In order to achieve this, all information concerning the loads and knowledge of the types of distribution systems are required [7].

In this project, an electrical power is transmitted from consumer switchgear room to each offices or tenants using cables, bus duct and combination of cables and bus duct. Both of these types are run through in electrical riser in the building on a cable tray. The effectiveness of the cables and bus ducts are important to voltage drop for a distribution system.

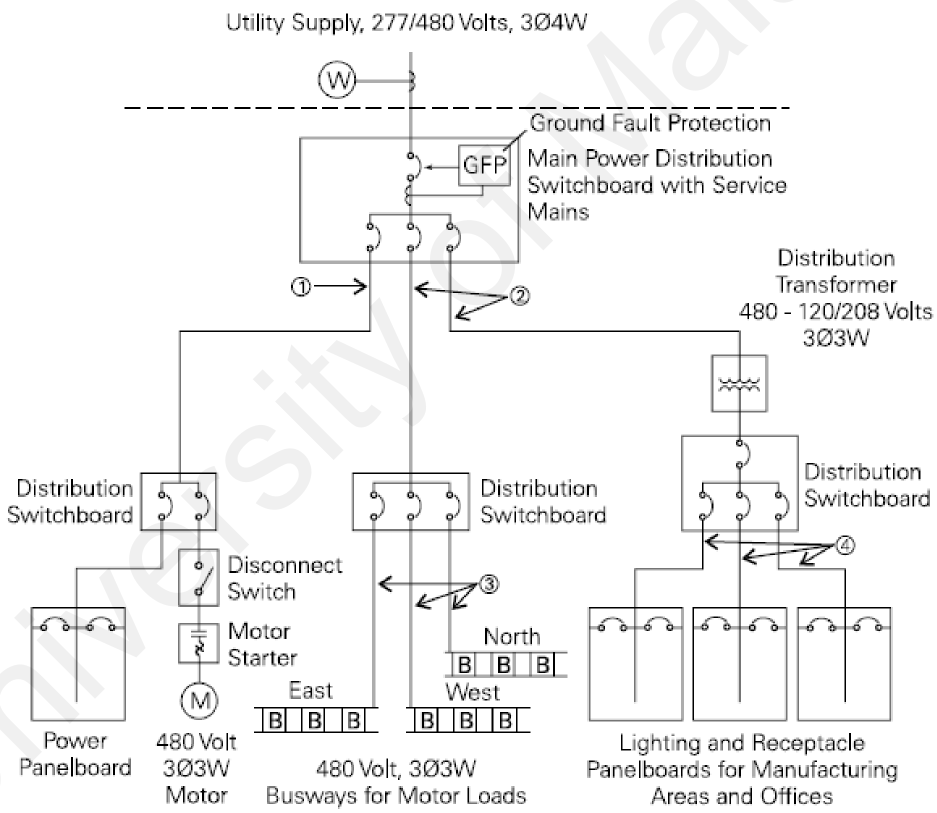

Figure 2.1: Power distribution layout

2.2.1 Distribution System Using Cables

For electrical distribution systems, either cables or bus ducts and combination of cables and bus ducts can be used to delegate the electrical energy from consumer switchgear room to each end user. The selection of the type of cables used depends on the situation and location. This is where the collection data of the cables, installation surroundings and the load play a vital role. Also, the effectiveness of cable sizing and model for building services can be developed.

In this project, XLPE/PVC cable is preferred because it has better electrical and physical properties. It is being used extensively in medium and high voltage cables. XLPE/PVC insulation can be safely used with conductor temperature up to 90°C, which increases the useful current rating especially when ambient temperature is high. Ease of installation and maintenance in electrical riser are simpler in comparison with other kinds of cables. Details of the cable are illustrated in Figure 2.2.

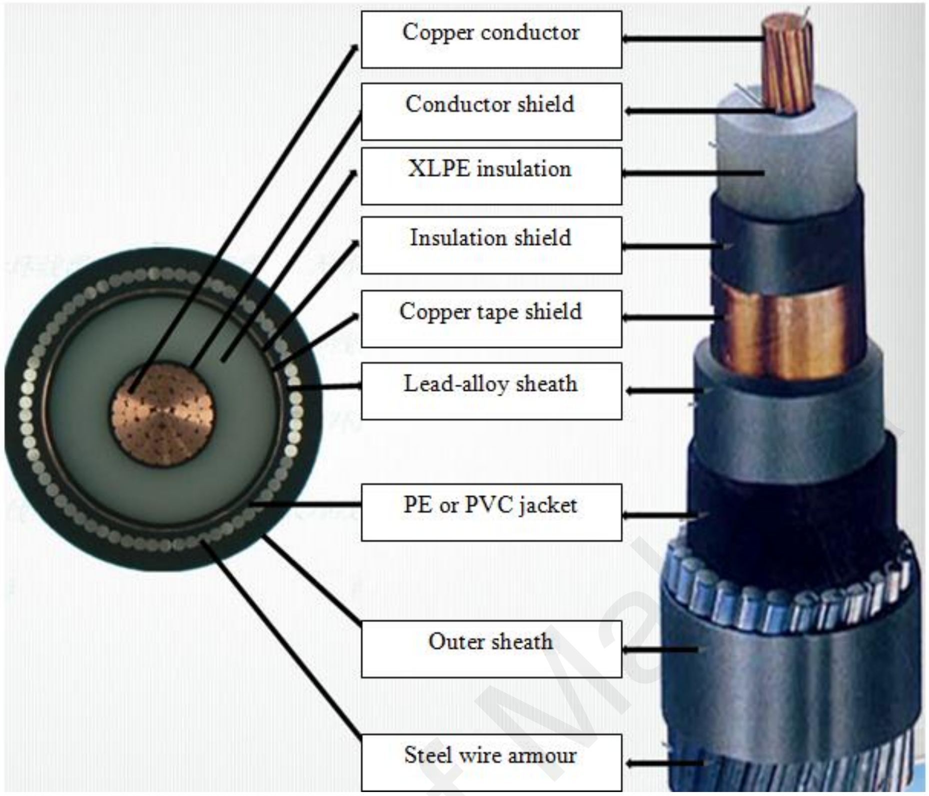

Figure 2.2: Details of XLPE/PVC cable

First and foremost, cable sizing is important to function endlessly under full load condition without being damaged. Moreover, it is necessary to hold up the worst short circuit current flow and ensure that the protective devices are effective during an earth fault. To ensure that, the supply to the load must be with a suitable voltage and able to avoid excessive voltage drops [1].

In addition, it is crucial to find the current carrying capacity (Amp) and voltage drop per ampere meter (mV/A/m) of the cable [8]. The current carrying capacity of a cable is the maximum current that can flow continuously through a cable without damaging the cable insulation and other components [9]. Short circuit temperature rise and earth fault loop impedance are significant factors to verify the cable size.

2.2.2 Distribution System Using Bus duct

A bus duct is used within electrical installations for distributing power from a supply point to a number of output circuits. They are used in a variety of configurations ranging from vertical risers, carrying current to each floor of a multi-story building, to bars used entirely within a distribution panel or within an industrial process. Figure 2.3 shows an example of power distribution using a bus duct in a building from a main switch room.

Busbar trunking system (BBT) performs the function of transporting current from one point to the other. BBT can tap off power to switchgear for further distribution using tap of boxes. In comparison to cables, BBT can serve as distribution panels at different stages, which means at the floor of a building. BBT continues as a single system to replace cables and distribution boards at floor level for commercial or industrial buildings. Busbar trunking system also provides an enhanced solution to power transmission and distribution in buildings and industries [10].

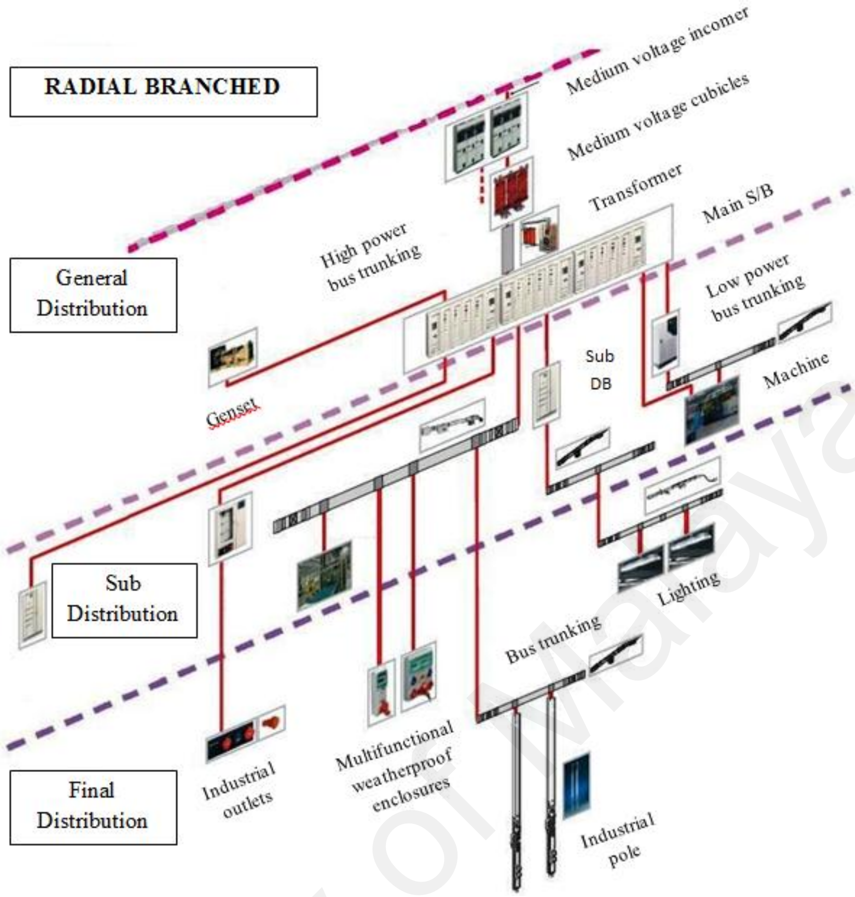

Figure 2.3: Power distribution using bus duct

2.2.3 Distribution System Using Combination of Cables and Bus duct

Power distribution systems used in commercial building and industrial locations are complex and occasionally design engineers use the combination of cables and bus duct in one system [11]. In this project, outgoing from switchgear panel is using cables and vertical in riser is using bus duct system, grouping 5 levels per one riser. This design is applied due to reduction of the cost for budgetary and also to control the voltage drop for the cables.

Vertical bus system is preferred in this project and used in vertical formation to supply individual floors of a high rise building as shown in Figure 2.3 and Figure 2.4.

Installation and maintenance of vertical formation is easy in electrical riser. This is much neater arrangement than using cables and running numerous lengths of them to each floor, which may not only be unwieldy but also more difficult to terminate and to locate faults [12]. This system is a normal practice in industry to distribute electrical power energy in high riser in a building.

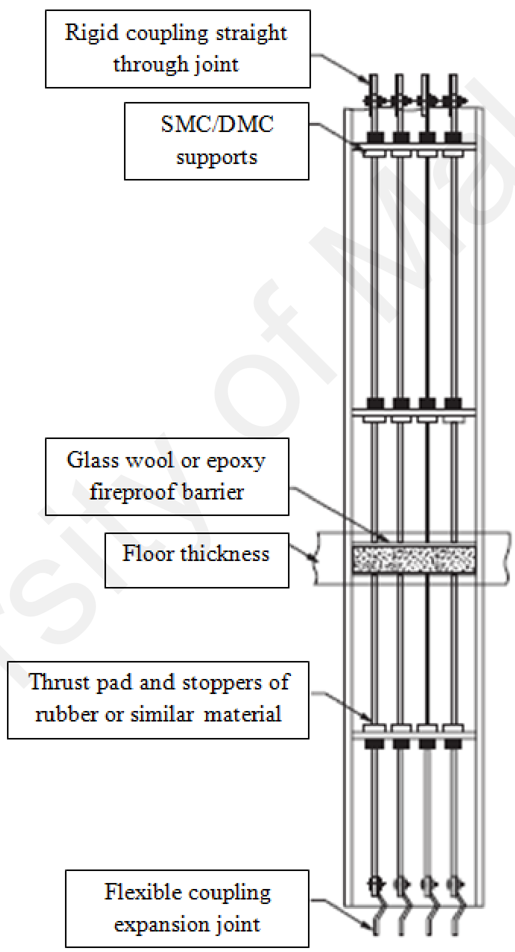

Figure 2.4: Front elevation of bus duct in an electrical riser

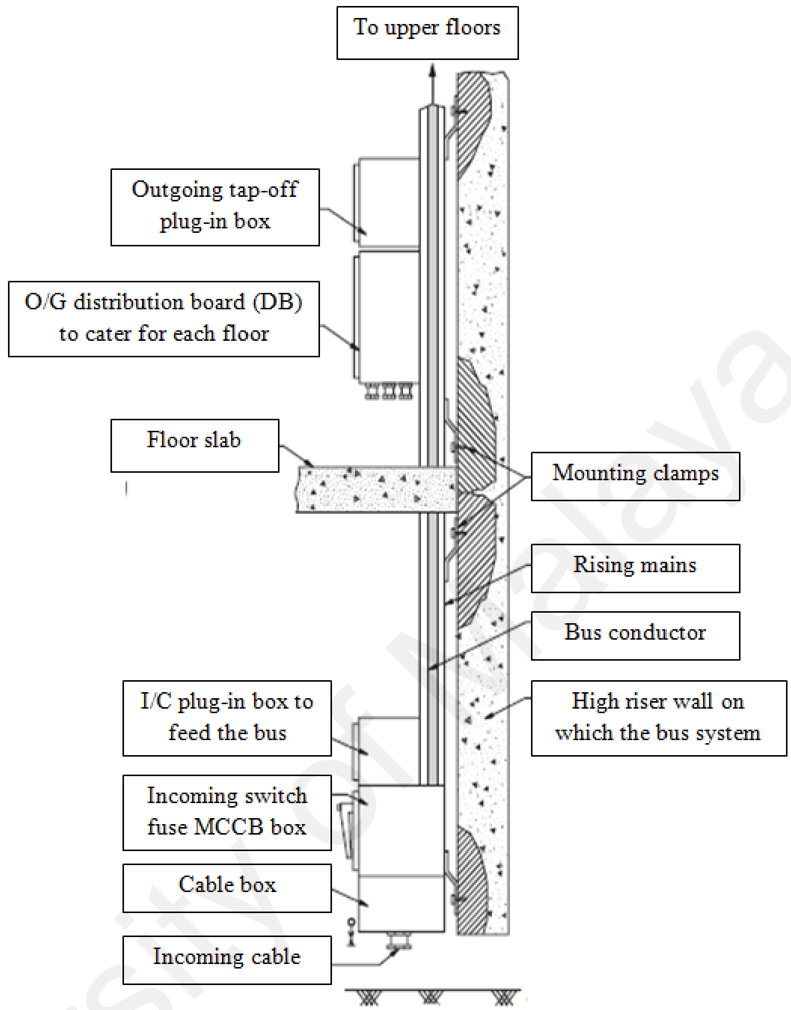

Figure 2.5: Side elevation of bus duct in an electrical riser

2.3 Protection Equipment

In power distribution system network, a circuit breaker is one of protection equipment widely used in electrical transmission and distribution system. It is very important because when there is a fault happens, the circuit breaker isolates the faulty area. Hence, extremely high currents do not flow into the whole distribution system, which damage related electrical components such as cable, bus duct, etc. Circuit breaker must function in normal and abnormal conditions and must accommodate short circuits and outages [13]. Obviously, a circuit breaker is used for switching and protection of the system involved.

For voltage applications below 450V, Air Circuit Breaker (ACB) is usually used in commercial buildings and industries as shown in Figure 2.6. ACB is an electrical device used to provide overcurrent and short circuit current protection for electrical circuits over 800 Amps to 10,000 Amps. The selection of ACB size depends on the total load current, I_{load} carrying for each system itself. During design stage, design engineer must be aware about these information and data and implementation of the circuit breaker on that system in real distribution system site.

Figure 2.6: Air circuit breaker devices

2.4. Voltage Drop Calculation

A voltage drop in electrical power distribution system is mainly caused by cables, transformers and motors. Voltage drop happens when load current (I_{load}) flows through a conductor or transformer having a finite impedance. Severe voltage drop will result in motor failures, dimming of lamps and CPU shutdown. Voltage drop calculation is important to system designer for maintaining nominal voltage at servicing sides. According to Suruhanjaya Tenaga, the voltage drop must not exceed 4% of the supply voltage.

$$4\% < V_{drop} \rightarrow \text{Suruhanjaya Tenaga}$$

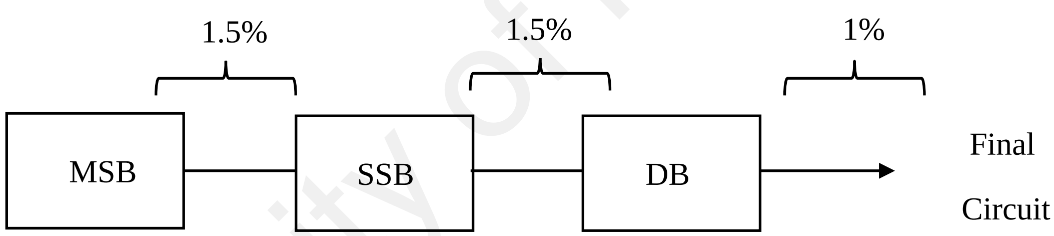

Figure 2.7: Illustrated voltage drop required by Suruhanjaya Tenaga

2.5 Conventional Method

Historically, manual calculation and Excel software are rarely used for the measurement and calculation during design stage to obtain the basic measurement such as total connected load, breaker current and voltage drop. All information and data gained should be keyed into Excel software according to respective division with each formulation. The most important part on this software is demand estimation. Maximum demand is calculated from the load at the receiving terminal averaged over a specified interval of time. Interval of time can be 15 minutes, 30 minutes and 60 minutes. In Malaysia, it is 30 minutes as shown in Figure 2.7.

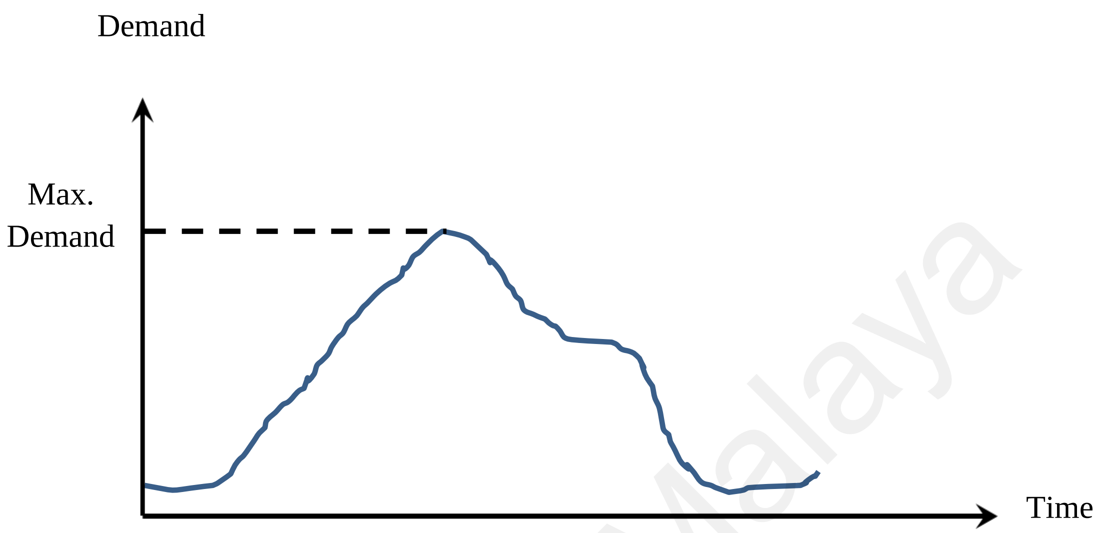

Figure 2.8: Demand estimation

The estimation of the maximum load demand is for determining the specifications of the wiring equipment and subsequently to prepare the electrical installation plans. From the demand estimation obtained, the measurement and calculation of load current (I_{load}), current breaker (I_{cb}) and voltage drop (V_d) can be done while ensuring an economic and reliable design within the permitted voltage drop limits. Thus, the selection of cables or busduct and sizes can be determined and implemented into the system designed by a design engineer. Hence, the overall total cost can be defined from the material used.

2.6 Particle Swarm Optimization (PSO)

Particle swarm optimization or known as PSO is a type of iterative optimization method, which is based on evolution of solutions as represented by positions of particle in an *N* dimensional solution [14]. It was established that different variation of PSO is used for different types of applications [15]. The advantages of PSO are:

(a) PSO is based on intelligence and easy to implement, it can be applied into both sciencetific research and engineering use.
(b) PSO has no overlapping and mutation calculation.
(c) PSO adopts the real number code and it is decided directly by the solutions.

2.7 Genetic Algorithm (GA)

Figure 2.9 shows a flow chart of GA. A genetic algorithm (GA) is a technique used in computing to find exact or approximate solutions to optimization and search problems. GA, inspired from evolutions of living beings in successive generations is the most utilized method in the field of evolutionary electronics design [14]. Power consumption optimization of digital circuits using GA has been studied in [15], in which four main strategies for reducing power including *Vdd* assignment, *Vth* assignment, sizing and stack forcing are considered and optimized by means of GA. The advantages of GA are:

(a) Higher chances of getting optimal solution.
(b) GA supports multi-objectives optimization.
(c) GA is inherently parallel and easily distributed.

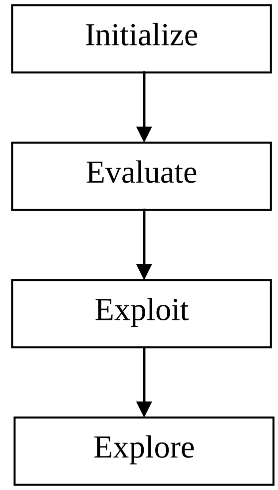

Figure 2.9: Flow chart of GA

2.8 Past Related Work

Ritula Thakur and Puneet Chawla (National Institute of Technical Teacher's Training & Researches and Ch. Devi Lal State Institute of Engineering & Technical) introduced project related to voltage drop calculations and design of urban distribution feeders in India as shown in Figure 2.8. This project was about the planning of the economical way to provide the electrical energy by State Electricity Boards to various consumers at minimum voltage drop and to reduce the regulation of voltage required for load points, tie-points. It was used to select respective kVA capacity of transformers and the installation of suitable capacitor banks with proper locations for improvement of power factor and harmonics. Different methods of reduction of distribution losses in the 11kV urban distribution feeder to improve the voltage profile was proposed [16].

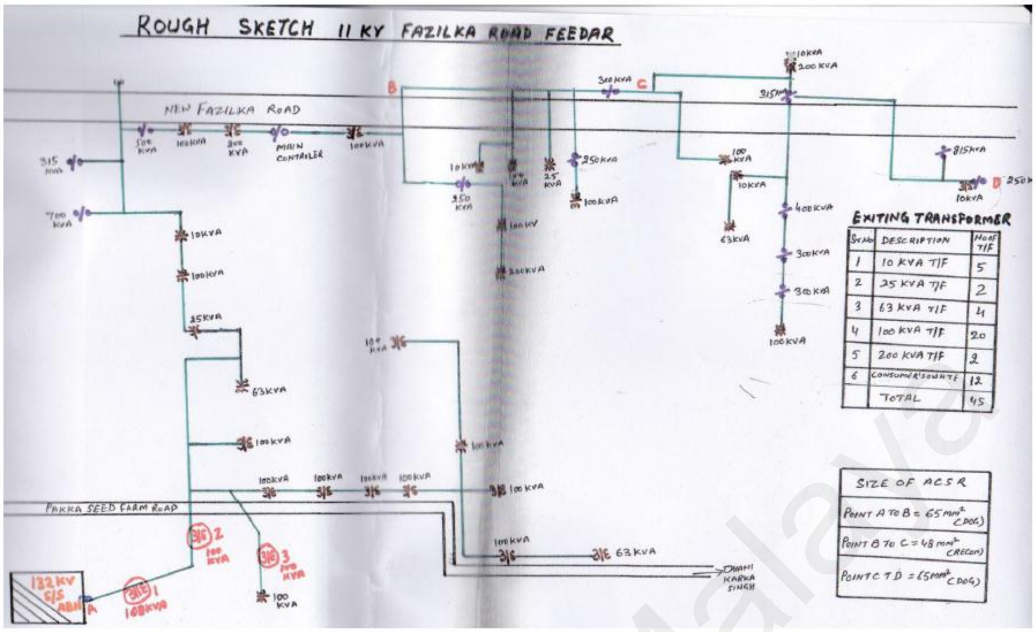

Figure 2.10: Design of urban distribution feeders in India [17]

Arvind Rajiv demonstrated how a power system is to be modelled with the given load within the building considered. Low voltage power distribution system was successfully designed by sizing the circuit breakers for each panel based on their total connected load. Figure 2.11 shows the most important factor that needs to be considered before modeling the power system. Voltage drop was calculated from the main distribution board until the final sub circuit. The cumulative percentage of voltage drop from the main distribution board up to the final sub circuits in the building does not exceed 4% of the nominal mortage of the electric supply ensured [17]. It is used to make sure that the design was in compliance to the regulation of the electricity authority.

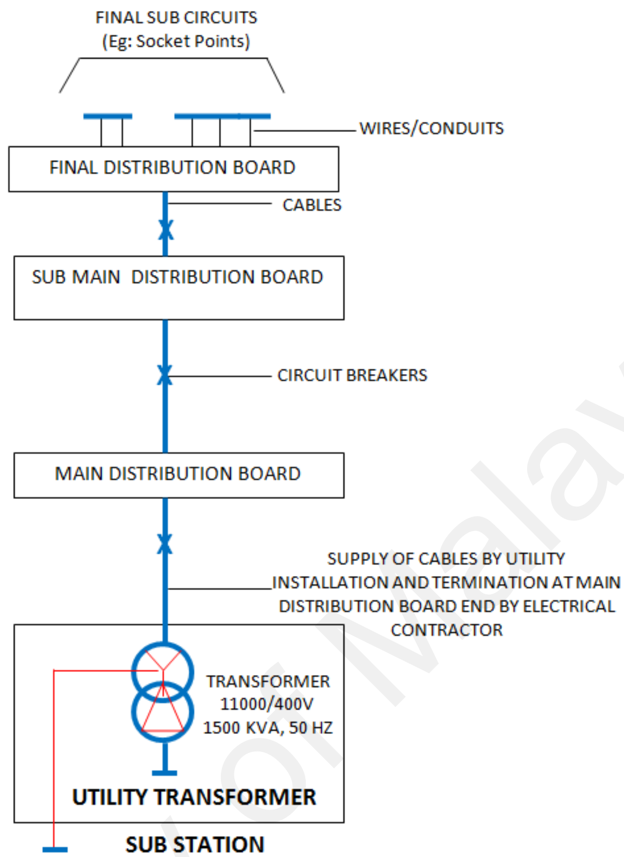

Figure 2.11: Stages of power flow from substation to final sub circuits

A new hybrid algorithm, which combines the advantages of GA, PSO and CLS for designing digital logic circuits, was proposed in [18]. Two cases have been investigated, which are with and without wiring term by using CGAPSO. It can be concluded that the inclusion of wiring term had considerable positive effect on the final circuit.

Researchers in [19] have demonstrated the total owning cost (TOC) evaluation by conventional methods compared to the results obtained after optimizing design variable using PSO and GA. The results showed that both PSO and GA work well for optimal design of transformer but somehow minimization using PSO shows better results.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter explains the electrical design concept and parameters to be optimized, which are cables, bus ducts and set of cable and bus ducts. Figure 3.1 depicts the workflow of this project.

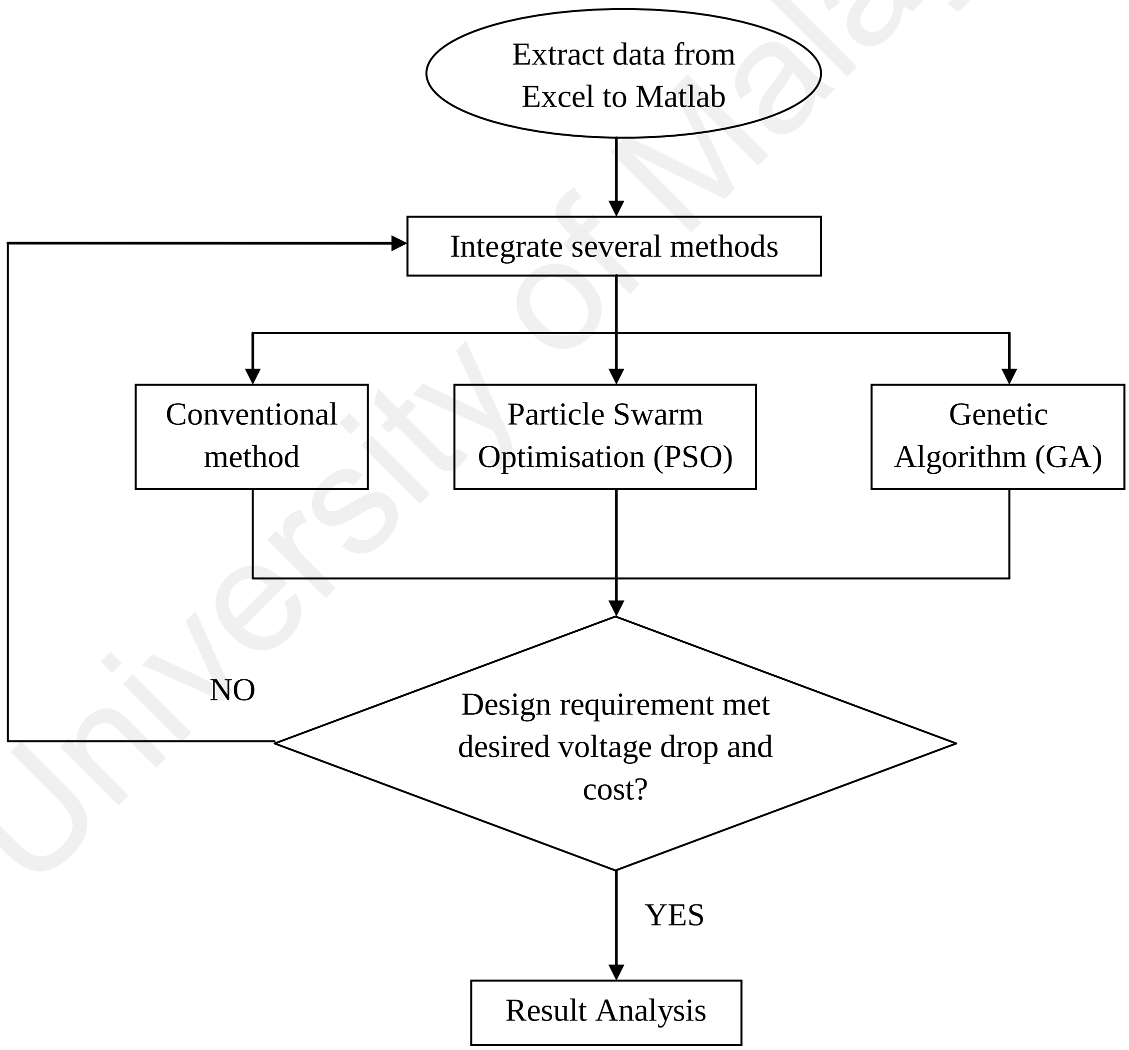

Figure 3.1: Flow Chart of Electrical Design in building

Initially, the data collected was extracted from Excel into Matlab workspace. In addition, several methods are also integrated in order to design electrical designs that are low voltage drop with minimal cost. To satisfy the design requirement, optimisation techniques were employed. Three parameters to be optimized are cable, bus duct and combination of cable and bus duct. They were optimized to obtain low voltage drop and low cost of electrical design in a building. In order to validate the simulation results, the data was compared with three different methods which are conventional method, particle swarm optimisation and genetic algorithm method.

3.2 Parameters to be optimized

In order to obtain minimum voltage drop and lowest costs in electrical design, there are several parameters need to be considered and assigned first. Those parameters are cables, bus ducts and set of cables and bus ducts have been used in this project.

3.2.1 Voltage drop calculation

Commonly, voltage drop on electrical distribution system is mainly caused by cables, transformers and motors. The voltage drop between the origin of the customer's installation and the equipment shall not exceed 4% of the nominal voltage of the installation. Voltage drop during temporary conditions such as motor starting can be exempted from this requirement. The approximation of voltage drop in this project can be calculated using

$$|V_{drop}| = |I_b| \text{ x } [R_L \text{ x } cos\theta - X_L \text{ x } sin\theta] \quad (3.1)$$

where;

R_L = Circuit resistance in Ohms

X_L = Circuit reactance in Ohms

I_b = Design current/ line current

θ = Phase angle of line current

3.2.2 Cable Selection and Sizing

Cable sizing is a very crucial factor at design stage. Initially, the data about the cables, installation environment and the load collected. In addition, it is important to find the current carrying capacity (A) and the voltage drop per ampere meter ($\frac{\text{mV}}{\text{A}}/\text{m}$) of the cable. Figure 3.2 shows the steps to determine the cable sizing and voltage drop. The derating factors for a range of installation conditions are provided by International Standards and Cable Manufacturers. The installed current rating is calculated by multiplying the base current rating with each of the derating factors as follows:

$$I_c = I_b \text{ x } k_d \quad (3.2)$$

where;

I_c = Installed current rating

I_b = Base current rating

k_d = Products of all the derating factors.

Figure 3.2 shows a flow chart to determine cable sizing and voltage drop. The cable needs only to be sized to cater for the full load current of the electrical wiring design plans. The selected cable must be capable of delivering the electrical energy efficiently to consumer for the building. Besides that, the cable size allows it to carry the current without heating the cable. For design engineers, they must know how to select the correct cable for electrical installation. According to the Malaysian standard, the selection of the cable is based on

$$I_{load} < I_{breaker} < I_{cable} \tag{3.3}$$

where;

I_{load} = Load current or designed current

$I_{breaker}$ = Current breaker

I_{cable} = Current cable

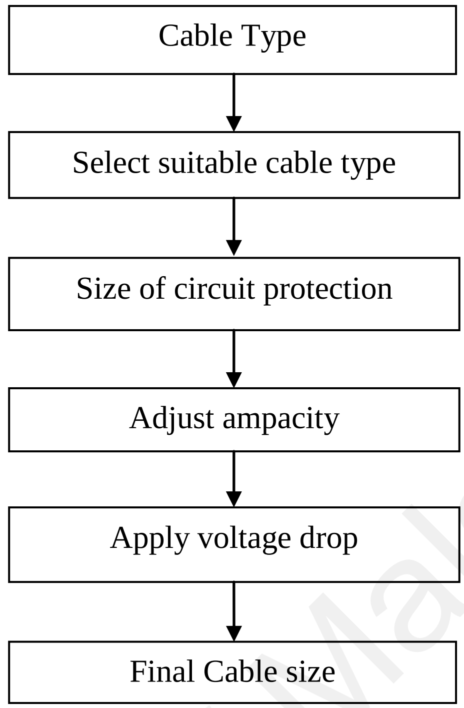

Figure 3.2: Flow chart to determine cable sizing and voltage drop

Table 3.1 lists the details of good cable insulation properties. The proposed cable in this project is XLPE/PVC Cu cable as shown in Figure 3.3 due to it meets the requirement of a good cable. In this project, the 600/1000V XLPE/PVC cable is used for delivering an electrical power from switchgear room to each riser. XLPE/PVC insulation is selected based on the surrounding conditions of the installation such as the ability to withstand the surrounding temperatures and the ability to provide mechanical protection. The insulation of XLPE and PVC shall be complied and approved by IEC and standard bodies.

Table 3.1: Good cable insulation properties

Properties	Details
Electrical	- Low dielectric constant and power - Partial dischage (PD) levels are low - High dielectric strength and insulation resistence
Mechanical	- Does not become stiff and brittle when operates at low temperature - Good elongation and tensile strength and toughness to withstand handling during installation and service - Good rupture strength, elongation, elastic modulus and tear strength
Thermal	- Excellent resistance to ageing at high temperature and chemicals

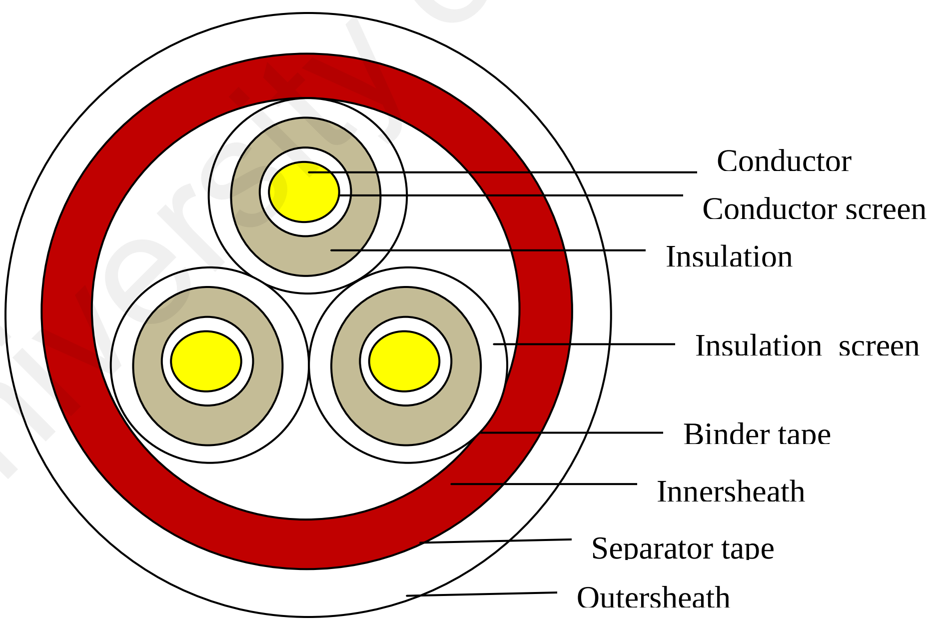

Figure 3.3: Medium voltage three-core XLPE insulated double-sheath power cable

3.2.3 Selection of bus duct

This project used busbar trunking with 400V, 3 phase, 4 wire and 50Hz system. The system is fitted with an integral earthing bar outside enclosure. For busbar trunking system serving for the loads with harmonics, particularly the UPS loads, lighting (normal and essential) loads, AHU loads and anything considered during design stage, the neutral bar shall be sized at 175% of the phase conductor.

A bus system design can be designed for one of the following types, depending upon its application such as rising mains (vertical bus duct system) and overhead bus (horizontal bus duct system). The selected busbar trunking is a metal clad, fully insulated and sandwiched type. Table 3.2 shows the basic construction details for a bus duct.

Table 3.2: Basic construction details for a bus duct

Items Properties	Details
Housing	- The enclosure of the busbar trunking system is rigidly constructed from electrogalvanised sheet steel of not less than 1.6mm thick and coated with epoxy powder paint and aluminium sheet. - Totally enclosed type with degree of protection not less than IP42 of IEC 60529 for indoor installation. - The number of fixing points shall be in accordance with the manufacturer's recommendation. - The busway is adequately earthed.
Busbar	- There shall be three (3) of equal size for phase and 175% of the phase conductor size for neutral busbar. - The busbar is made of full round edge rectangular section

	and hard drawn high conductivity. - Each busbar is sheated over its length with insulation class F, 155 Degrees Celcius rated insulating material with thickness 1.6mm by extrussion process. The temperature rise at any point along the bus must not exceed 55-Degree Celcius above the ambient temperature of 40 Degree Celcius when operating at its 100% rated current. - Busbar section of feeder type and plug in type are to be provided at the necessary tap offs.
Other accessories	- Joints bolts is not used for busbar jointing but to clamp busbars at between lengths and tightened to the strength figure. It also has a secure maximum contact area of clamping at between the busway length to reduce heat temperature during operation. - Tap off opening for vertical bus duct system is consistently located at the same heigh above the floor at every level to achieve a uniform layout arrangement. - Termination accessories as a cables earthing or leaving terminal boxes are to be provided with seperate terminations so that any cable out of a number of such cables can be removed or replaced without disturbing the remainder.

3.2.4 Protection Equipment

In this project, protection equipment is designed by an engineer and applied to provide proper discrimination between faulty and healthy circuits. They are to remain inoperative during transient phenomena, which may arise during switching or other disturbance to the system. The design of the protection is not limited to individual equipment alone but it also needs to be coordinated so that good performance can be achieved throughout the system starting from the TNB incoming feeders to the individual final sub-circuits. The protection system performance has to reflect good zone selectivity, relay stability, speed with proper discrimination and reasonable sensitivity without any loss of reliability and maintainability [20].

At design stage, all calculations are carried out, checked the adequacy of all equipment short-circuit ratings, provided the best protective device and coordinated all protective device in the system. Protection for the various circuits should not limit. Table 3.3 shows the circuit type and protection equipment required for the system designed.

Table 3.3: Circuit type and protection equipment

Circuit Type	**Protection Requirement**
TNB incoming 11kV	Overcurrent and earth fault
Building 11kV cables	Overcurrent and earth fault
11/0.433kV transformers	Overcurrent, earth fault and winding temperature
Incoming to low voltage main switchboard	Overcurrent and earth fault
Outgoing from low voltage main switchboard to sub-switchboards or distribution board	Above 400A OC/EF 60A to 400A ELR 40A and below RCD
Incoming to sub-switchboard or distribution board	Above 400A OC/EF 60A to 400A ELR 40A and below RCD

3.2.4.1 Air Circuit Breaker

The main focus for protection equipment in this project is an air circuit breaker. Electrical circuit breaker reacts for controlling and protecting electrical power system respectively either it operated manually and automatically. The fundamental characteristics of a circuit-breaker are rated voltage, rated current, tripping current level adjustment ranges for overload protection and short circuit current breaking rating. Table 3.4 shows the main part of a circuit breaker and its four essential functions.

Table 3.4: Part of a circuit breaker and functions

Main part	Function
Circuit breaking component	- Comprises of the fixed and moving contacts and the arc-dividing chamber.
Latch mechanism	- Latching mechanism, which becomes unlatched by the tripping device on detection of abnormal current conditions. - This mechanism is also linked to the operation handle of the breaker.
Trip mechanism	- A thermal-magnetic device, in which a thermally-operated bi-metal strip detects an overload condition while an electromagnetic striker pin operates at current levels reached in short-circuit condition. - An electronic relay operated from current transformers, one of which is installed on each phase.

Space allocation	- A space allocated to the several types of terminal currently used for main power circuit conductors.

A simplified model with three operating functions shown for a thermal magnetic circuit breaker is shown in Figure 3.4. It is the commonly used as a circuit breaker.

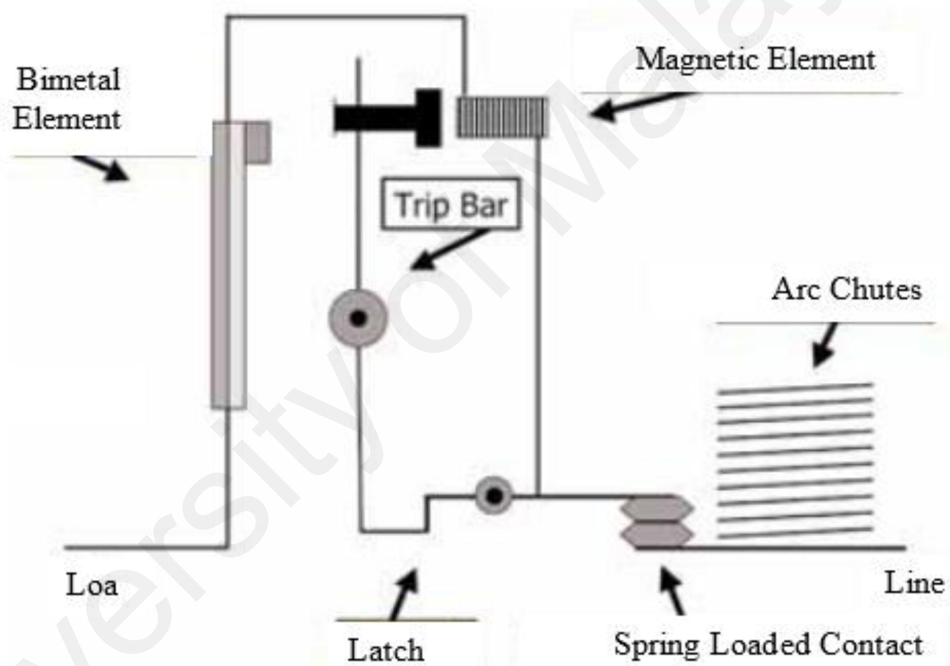

Figure 3.4: Simplified model with three functions

An air circuit breaker used in this project is the air-break type suitable for indoor use and outdoor use, complete with all necessary instruments, transformers, closing and tripping devices and others protective instruments. It is easily accessible and operable from the front and provided with padlocking facilities. Both phase and neutral switching are required. The selection of circuit breaker is complying with IEC 60947-2 regarding to their test performance and the number of operating cycles. It has also a rated short-circuit making and breaking capacity specified and is trip-free.

Locking facilities are provided on the circuit breaker and control switch. At any position, the circuit breaker can be prevented from being directly and manually operated. A mechanical and electrical lockout is provided to prevent closing of the breaker after an overcurrent trip. Besides, all operating mechanisms have mechanical ‘ON’ and ‘OFF’ indicator lamps. ACB needs a motor-charged operating mechanism, which shall be arranged so that the release of the spring to close the circuit breaker can only be done by deliberate action. Remote controlled switching has also to be provided for motor-charged operating mechanism ACB.

3.2.5 Distribution Methods

The distribution system involved is to distribute electrical power from switchgear room to consumer in a high-rise building. In large buildings, the type of distribution depends on the building type, dimension, the length of supply cables and the loads. The distribution system can be divided into the vertical supply system (rising mains) and the horizontal supply (distribution at each floor level). The arrangement of the rising mains depends on the size and shape of the building and suitable size of shafts for installing cables and bus ducts must be provided.

Modern electrical installations are increasingly in demand on all products of the electrical equipment manufacturers. Products must have reliable service life, adaptability to new requirements, low installation costs, low maintenance costs, inherent safety features and other. Nowadays, there are various methods to distribute electrical power system such as by using cables, bus ducts and combination of cables and bus ducts depending upon its application. Distribution system requires economical system to provide electrical energy at suitable prize and at a minimum voltage drop to reduce the voltage regulation.

3.2.5.1 Distribution using Cable

Figure 3.5 shows a schematic diagram of an electrical system for distribution using cables and this method is conventionally used nowadays. Lower cost can be obtained by using cables. However, it is difficult to control the voltage drop for high rise buildings because a cable has its current carrying capacity and voltage drop. The selection of power cable and types of cables with the sizing of the conductors for specific applications is a very essential part of the plan of any electrical system.

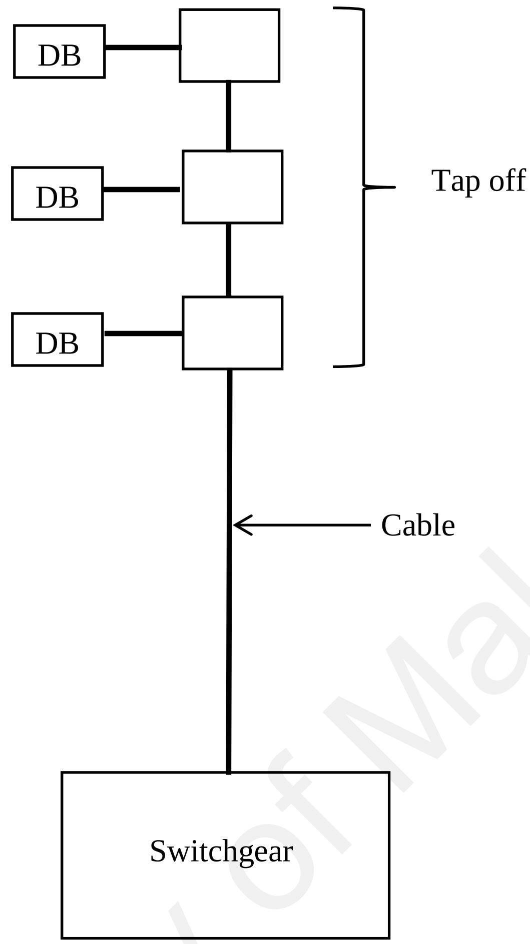

Figure 3.5: Schematic diagram of an electrical system using cables

3.2.5.2 Distribution using Bus duct

Modern electrical distribution systems using bus ducts are widely compared to cables, depending on the condition and application of the building. The advantage of using a bus duct is easy and quick for initial installation. A compact design of a bus duct system provides high space of efficiency up to 50% compared to the cables. A schematic diagram of a bus duct system is shown in Figure 3.6. However, the cost of the electrical system design using bus duct is higher compared to the cables.

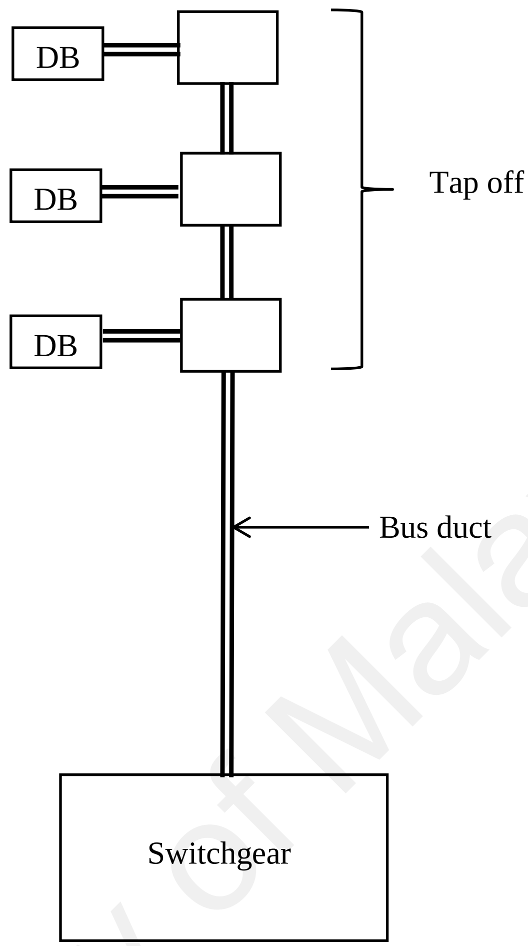

Figure 3.6: Schematic diagram of an electrical system using bus duct

3.2.5.3 Distribution using Cables and Bus duct

This project proposed a combination of cables and bus ducts in order to obtain a minimum voltage drop with lower cost. The cables are used from an outgoing switchgear room running on the cable ladder or tray to the electrical riser. After that, the vertical bus duct is used continuously in the electrical riser for delivering electrical power to consumers or tenants in the building. Figure 3.7 shows the schematic a combination of cables and bus duct used for the electrical system in this work.

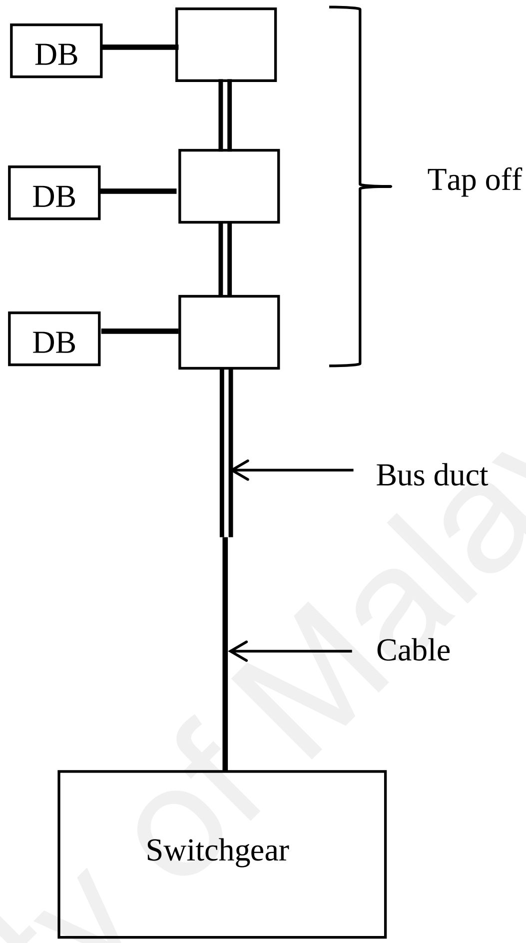

Figure 3.7: Schematic diagram of an electrical system using cable and bus duct

3.3 Particle swarm optimization (PSO)

PSO is a population based stochastic optimization technique inspired by social behaviour of bird flocking or fish schooling. The system was loaded with a population of random solutions and search for optimal by updating generations. The potential solutions go through the problem space and the current optimum particles are followed. A flow chart of PSO algorithm is depicted in Figure 3.8. A population of particles with random position velocities and P_{best} are initialized. To obtain desired optimization of fitness function, each particle was evaluated and compared with its best previous position. The velocity and position of each particle were changed. At the end of the iteration, the optimal solution was obtained.

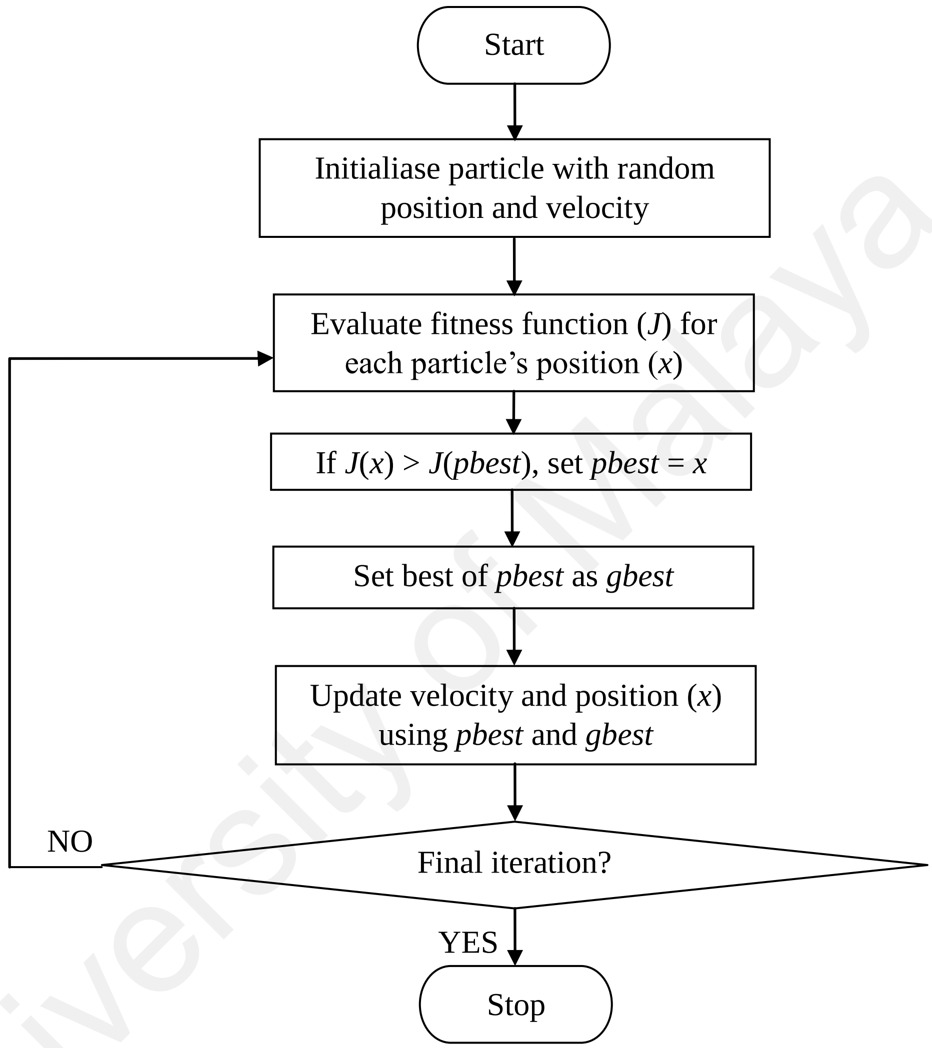

Figure 3.8: Flowchart of PSO algorithm

3.4 Genetic Algorithm (GA)

In GA, individuals, which are the population of candidate solutions, have a set of chromosomes. The proposed solutions are defined as the population. They are represented in binary as strings of 0s and 1s. The evolution of the algorithm is used to obtain the optimized solutions through genetic operators, which are *selection, crossover* and *mutation*. A flowchart of GA algorithm used in this work is shown in Figure 3.9.

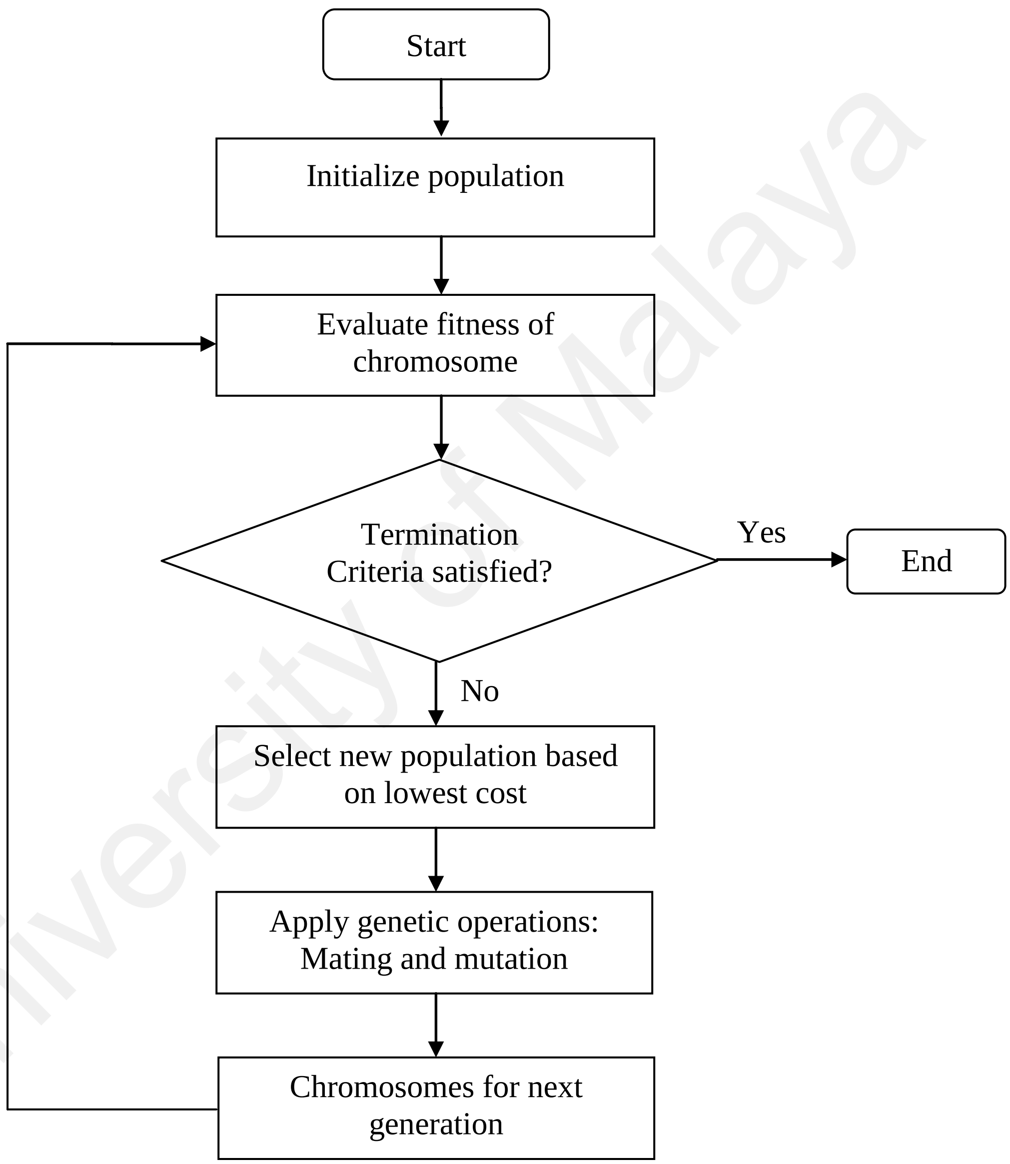

Figure 3.9: Flowchart of GA algorithm used in this work

The explanation of the steps in GA algorithm is as follows:

Initialization: Chromosome is also known as the population. The populations are randomly generated. The population is a matrix in this algorithm, which has *Npop* chromosomes. The matrix is defined as *Npop* x *Nbits*, where *Npop* is predefined and *Nbits* is the number of variables.

Evaluation: The objective function is used to evaluate the fitness of each of the chromosomes. The initial parameters are set to run in the technique to obtain the estimated values of the objective function.

Selection: The chromosomes with the lowest cost function are the fittest. They will survive while the others will be eliminated. The cost of *Npop* with its chromosomes is arranged from the lowest to the highest cost. To examine the number of chromosomes that is survived for the next generation, selection rate (*Xrate*) is used in this algorithm. The number of chromosomes which is remained for each generation is:

$$Nkeep = XrateNpop \tag{3.3}$$

Crossover: Crossover in GA is defined as mating between individuals. Single point crossover is used in this algorithm. Mating is normally defined as pairing two parents to generate two new offspring. In single point crossover, the chromosomes of the parents are randomly picked from the first bit and the last bit. Single point crossover in mating is shown in Figure 3.10.

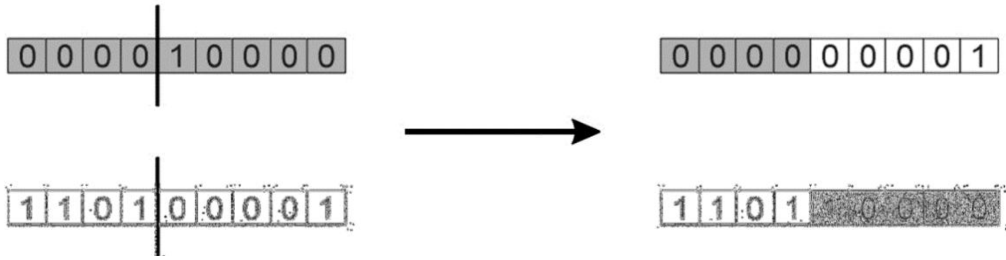

Figure 3.10: Single point crossover in mating [23]

Mutation: Mutation in GA is defined as a random modification, which will change the bits of some chromosomes. Random modification is applied to prevent earlier convergence of GA before the whole space is searched for its minimum cost. Traits are produced outside the original populations to remain the diversity of the population. Mutation will change one point of chromosome from 0 to 1 or 1 to 0. This point is picked randomly from the population matrix. The number of mutation is determined by

$$\#mutations = (Npop - 1) \text{ x } Nbits \text{ x } mutrate \quad (3.4)$$

Where,

mutrate is the rate of mutation.

Termination criterion: If the termination criterion is satisfied, the algorithm will stop and it will display the best solution and the best cost. Else, the algorithm will continue to update to achieve the minimum cost or the maximum number of iterations.

CHAPTER 4: RESULTS AND DATA ANALYSIS

4.1 Introduction

This chapter reported the results obtained from the work. To find the minimum cost and lowest voltage drop on electrical wiring design in a building, particle swarm optimization and genetic algorithm methods were employed. These results were compared with conventional method. At the end of the analysis, the performance of particle swarm optimization and genetic algorithm method was compared to determine which method is more suitable for electrical wiring design in a building.

4.2 Data

First, certain data or parameters were assigned. An electrical design goes through several important stages of development. Then, a design engineer defines and designs each component such as general office area, specialized machinery and distribution equipment based on recognized industry standards. In this project, these data and parameters were obtained from the supplier catalogues.

4.2.1 Power Demand Data

Every electrical design has unique requirements, depending on the scope of the project. In this project, the power demand data obtained from datasheet of project is done at working place. There are four risers with different power demand data. However, the data was analyzed only for Riser A. Table 4.1 shows all power demand data referred to the datasheet in the office.

Table 4.1: Power demand data

No	Riser	Connected Load (kW)	Maximum Demand (kW)
1	A	667.50	534
2	B	628.56	502.85
3	C	667.50	534
4	D	556.25	445

4.2.2 Cable Data

In this project, XLPE/PVC cable is used to distribute electrical power from switchgear room to consumer. Cable manufacturers usually provide the ampacity of the cables in their datasheet. These values are calculated based on a predefined set of assumption, usually in accordance to certain international standards such as IEC-287. The assumptions are usually provided in the datasheet for user's reference. Table 4.2 shows a cable datasheet for XLPE/PVC cable.

Table 4.2: Cable datasheet for XLPE/PVC cable.

Cable	Carry Amp (A)	Voltage Drop (60 Degree) (V)	Description	Size (mm^2)
XP70	279.00	0.620	4 x 1C 70mm2 XLPE + E	70
XP95	341.00	0.460	4 x 1C 95mm2 XLPE + E	95

XP120	398.00	0.380	4 x 1C 120mm2 XLPE + E	120
XP150	461.00	0.320	4 x 1C 150mm2 XLPE + E	150
XP185	530.00	0.280	4 x 1C 185mm2 XLPE + E	185
XP240	630.00	0.240	4 x 1C 240mm2 XLPE + E	240
XP300	730.00	0.210	4 x 1C 300mm2 XLPE + E	300
XP400	849.00	0.195	4 x 1C 400mm2 XLPE + E	400
XP500	973.00	0.180	4 x 1C 500mm2 XLPE + E	500
XP630	1115.00	0.170	4 x 1C 630mm2 XLPE + E	630

4.2.3 Busduct Data

Table 4.3: Bus duct datasheet

Bus	**Carry Amp (A)**	**Voltage Drop (60 Degree) (V)**	**R (60 Degree) (Ω)**	**X (Ω)**	**Z (Ω)**	**Description**	**Size (mm^2)**
B600	600	0.00131	0.705	0.229	0.7413	600 A - 4P + Integrated Earth	300
B800	800	0.00129	0.731	0.229	0.7660	800 A - 4P + Integrated Earth	330
B1000	1000	0.00093	0.52	0.177	0.5493	1000 A - 4P + Integrated Earth	450
B1200	1200	0.00076	0.41	0.138	0.4326	1200 A - 4P + Integrated Earth	600

B1500	1500	0.00060	0.355	0.113	0.3726	1500 A - 4P + Integrated Earth	750
B1600	1600	0.00051	0.287	0.095	0.3023	1600 A - 4P + Integrated Earth	900
B2000	2000	0.00041	0.228	0.085	0.2433	2000 A - 4P + Integrated Earth	1110
B2500	2500	0.00032	0.176	0.07	0.1894	2500 A - 4P + Integrated Earth	1440
B3200	3200	0.00026	0.145	0.056	0.1554	3200 A - 4P + Integrated Earth	1800
B3500	3500	0.00023	0.128	0.048	0.1367	3500 A - 4P + Integrated Earth	2100

Table 4.3 shows the busduct datasheet details and it is provided by busduct specialist. Busducts are used in commercial and industrial settings, both indoors and outdoors. Manufacturers deliver them in large segments for electrical contractors to connect and support. A variant type is low impedance busduct, which is designed to have lower voltage drop. In this project, the vertical busduct is used in electrical riser to distribute electrical power to consumer.

4.2.4 PSO Parameters

In PSO algorithm, the selection of the parameters is important in order to find the optimized parameter value for the voltage drop and costs. The maximum velocity affects the ability of the particle to escape from the local optimization and global best optimization.

These parameters are used for searching the global best and the optimum parameters of the voltage drop for this system. In PSO algorithm, the parameters are shown in Table 4.4.

Table 4.4 : Parameters value for PSO

Population Size	40
Number of Iteration	20
Velocity constant, c_1	0.12
Velocity constant, c_2	1.2
Inertia weight, w	0.9

4.2.5 GA Parameters

The selection of the next population by computation uses random number generators. At each step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the children for the next generation. The best point in the population approaches an optimal solution. Table 4.5 shows the parameter values used in GA.

Table 4.5: Parameter values for GA.

Population Size	40
Number of Iteration	20
Mutation Rate	0.2

Fraction	0.4
W1	0.6
W2	0.4
Varhi	[10 10 2 1]
Varlo	[1 1 1 1]

4.3 Results of electrical system design

In this project, the methods used are conventional method, PSO and GA. These methods were conducted using Matlab software. The results obtained are recorded and tabulated in tables. Finally, the results were compared between each other.

4.3.1 Conventional method

Conventional method is commonly used in industries today by using calculation in an Excel sheet. In this study, the initial data collected is extracted into Matlab coding based on the same calculation and mathematical formula in the Excel. Then, these data were run for several times and recorded in a table. The conventional method uses trial and error method, which means the selection of the parameters is done manually. This method is widely used in industries by design engineers but it takes a long time to select the best option. Table 4.6 shows the result from the conventional method, which used combination of cables and bus ducts.

Table 4.6: Result from conventional method

No. of run	Cable type	Busduct type	Cable Set	Busduct Set	Voltage Drop (%)	Total Costs (RM)
1	XP630	B1500	2	1	0.3299	105175
2	XP300	B600	2	1	0.4097	63661
3	XP300	B2500	2	1	0.4059	86101
4	XP300	B800	2	1	0.4096	65701
5	XP300	B1200	2	1	0.4076	71413
6	XP630	B1200	2	1	0.3305	102727
7	XP400	B1000	2	1	0.3793	76547
8	XP500	B3500	2	1	0.3477	112587
9	XP500	B1000	2	1	0.3504	87699
10	XP630	B1000	2	1	0.3312	100687
11	XP240	B2500	2	1	0.4637	79675
12	XP500	B1600	2	1	0.3488	94227
13	XP240	B1000	2	1	0.4660	62947

14	XP400	B600	2	1	0.3808	70835
15	XP240	B1600	2	1	0.4644	69475
16	XP500	B1200	2	1	0.3498	89739
17	XP630	B2000	2	1	0.3292	1133
18	XP630	B2500	2	1	0.3288	117415
19	XP240	B600	2	1	0.4675	57235
20	XP400	B800	2	1	0.3807	72875
21	XP300	B1600	2	1	0.4066	75901
22	XP240	B800	2	1	0.4674	59275
23	XP300	B2000	2	1	0.4063	82021
24	XP300	B1000	2	1	0.4082	69373

From Table 4.6, it can be seen that the results yield different voltage drop and cost according to the material applied and the size used. The summary of the selection is shown in Table 4.7.

Table 4.7: Summary of the result using conventional method

No	Cable size	Busduct size	Cable Set	Busduct Set	Voltage Drop (%)	Total Costs (RM)
1	XP240	B1000	2	1	0.4660	62947
2	XP300	B1000	2	1	0.4082	69373
3	XP400	B1000	2	1	0.3793	76547
4	XP500	B1000	2	1	0.3504	87699
5	XP630	B1000	2	1	0.3312	100687

From Table 4.7, it can be seen that the busduct is selected depending on the current design of the maximum demand during the planning stage. Meanwhile, the cable is selected based on the cable set for the current carrying capacity. Obviously, the size of the cable is affecting the total voltage drop and total cost.

4.3.2 PSO method

In PSO method, the current fitness was tried with three different functions. The first is minimisation of total voltage drop only. The second is minimisation of the total cost and finally is the combination of the voltage drop and total cost.

4.3.2.1 Minimizing the Total Cost

From Table 4.8, it can be seen that after 20 times of running the PSO code with fitness function of minimizing the total cost, the results show consistent value on the total cost. The total cost was minimized but the voltage drop was not minimized. Figure 4.1 shows the fastest time for the PSO to converge. The PSO method converges at second iteration.

Table 4.8: Results for PSO for minimizing the total cost

No. of run	Total Cost (RM)	Total Voltage Drop (%)
1	33 333	2.3945
2	33 333	2.3945
3	33 333	2.3945
4	33 333	2.3945
5	33 333	2.3945
6	33 333	2.3945
7	33 333	2.3945
8	33 333	2.3945
9	33 333	2.3945

10	33 333	2.3945
11	33 333	2.3945
12	33 333	2.3945
13	33 333	2.3945
14	33 333	2.3945
15	33 333	2.3945
16	33 333	2.3945
17	33 333	2.3945
18	33 333	2.3945
19	33 333	2.3945
20	33 333	2.3945

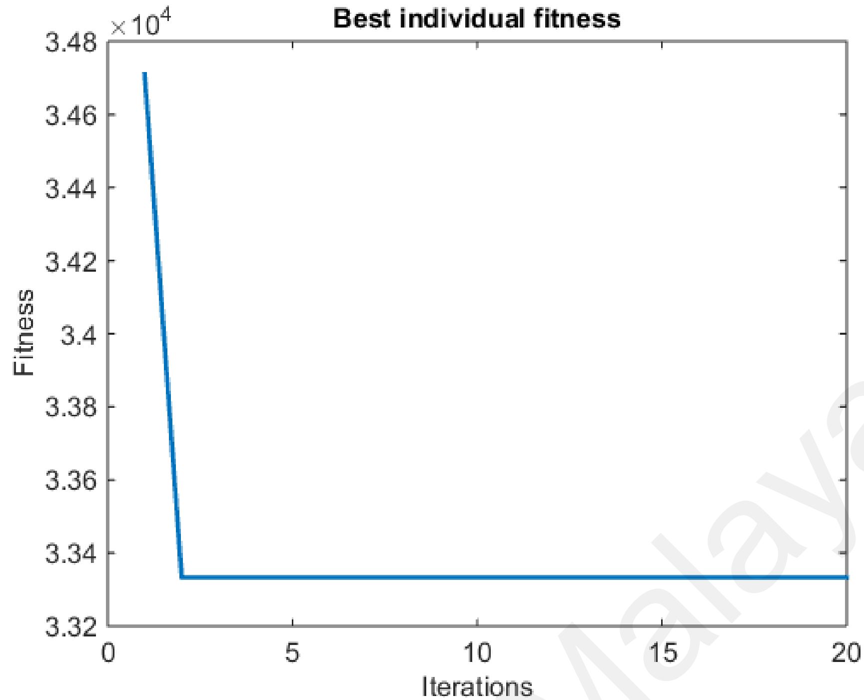

Figure 4.1: Convergence curve for PSO for minimizing the total cost

4.3.2.2 Minimizing the Total Voltage Drop

From Table 4.9, it can be seen that after 20 times of running the PSO code with fitness function of minimizing the total voltage drop, the total voltage drop was minimized but the total cost was not minimized. Figure 4.2 shows the fastest time for the PSO to converge. The PSO method converges at second iteration.

Table 4.9: Results for PSO for minimizing the total voltage drop

No. of run	**Total Voltage Drop (%)**	**Total Cost (RM)**
1	0.6175	76 683

2	0.6175	76 683
3	0.5404	81 001
4	0.5404	81 001
5	0.6175	76 683
6	0.6175	76 683
7	0.6175	76 683
8	0.6175	76 683
9	0.7331	74 575
10	0.6175	76 683
11	0.6175	76 683
12	0.5404	81 001
13	0.5404	81 001
14	0.5404	81 001
15	0.5404	81 001
16	0.5404	81 001

17	0.6175	76 683
18	0.7331	74 575
19	0.8873	71 107
20	0.5404	81 001

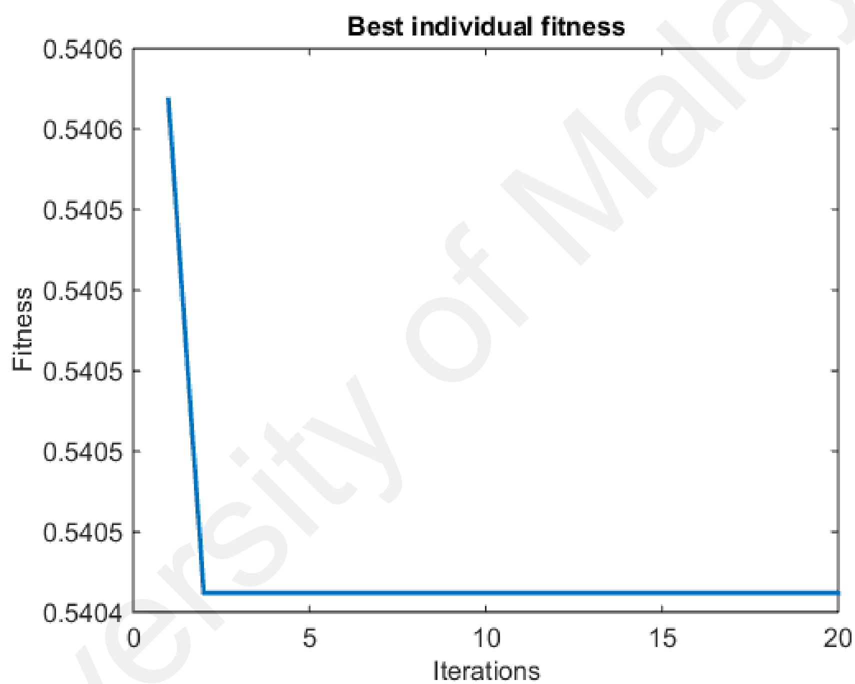

Figure 4.2: Convergence curve for PSO for minimizing the total voltage drop

4.3.2.3 Minimizing the Total Voltage Drop and Total Cost

From Table 4.10, it can be seen that after 20 times of running the PSO code with fitness function of minimizing the total voltage drop and total cost, the total voltage drop and cost were minimized. Figure 4.3 shows the fastest time for the PSO to converge. The PSO method converges at second iteration.

Table 4.10: Results for PSO for minimizing the total voltage drop and total cost

No. of run	Total Voltage Drop (%)	Total Cost (RM)
1	0.7373	43 975
2	0.8915	40 507
3	0.8915	40 507
4	0.7373	43 975
5	0.7373	43 975
6	1.1998	37 753
7	1.1998	37 753
8	0.8915	40 507
9	0.8915	40 507
10	0.8915	40 507
11	1.1998	37 753
12	0.7373	43 975

13	0.8915	40 507
14	0.7373	43 975
15	0.7373	43 975
16	0.7373	43 975
17	0.8915	40 507
18	1.1998	37 753
19	0.8915	40 507
20	1.1998	37 753

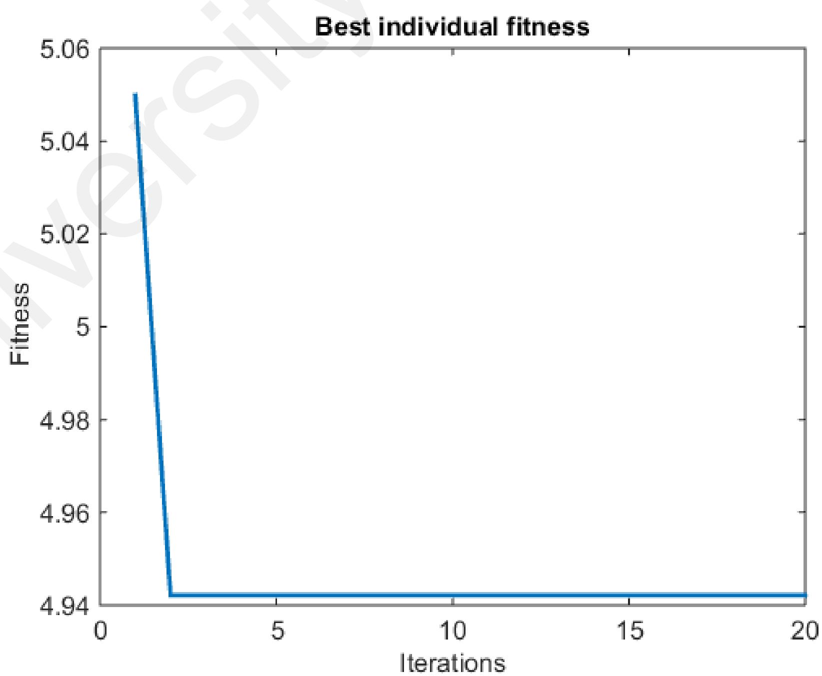

Figure 4.3: Convergence curve for PSO for minimizing the total voltage drop and total cost

4.3.3 GA method

In GA method, the current fitness was tried with three different functions. The first is minimisation of total voltage drop only. The second is minimisation of the total cost and finally is the combination of the voltage drop and total cost.

4.3.3.1 Minimizing the Total Cost

From Table 4.11, it can be seen that after 20 times of running the GA code with fitness function of minimizing the total cost, the total cost was minimized but the voltage drop was not minimized. Figures 4.4 and 4.5 show the fastest time for the GA to converge. The GA method converges at first iteration when the result is at total cost of RM 34 710 and converges at third iteration when the result is at total cost of RM 33 333.

Table 4.11: Results for GA for minimizing the total cost

No. of run	Total Cost (RM)	Total Voltage Drop (%)
1	34 710	1.7779
2	33 333	2.3945
3	33 333	2.3945
4	33 333	2.3945
5	33 333	2.3945

6	33 333	2.3945
7	34 710	1.7779
8	33 333	2.3945
9	33 333	2.3945
10	33 333	2.3945
11	33 333	2.3945
12	33 333	2.3945
13	33 333	2.3945
14	33 333	2.3945
15	33 333	2.3945
16	33 333	2.3945
17	34 710	1.7779
18	33 333	2.3945
19	33 333	2.3945
20	33 333	2.3945

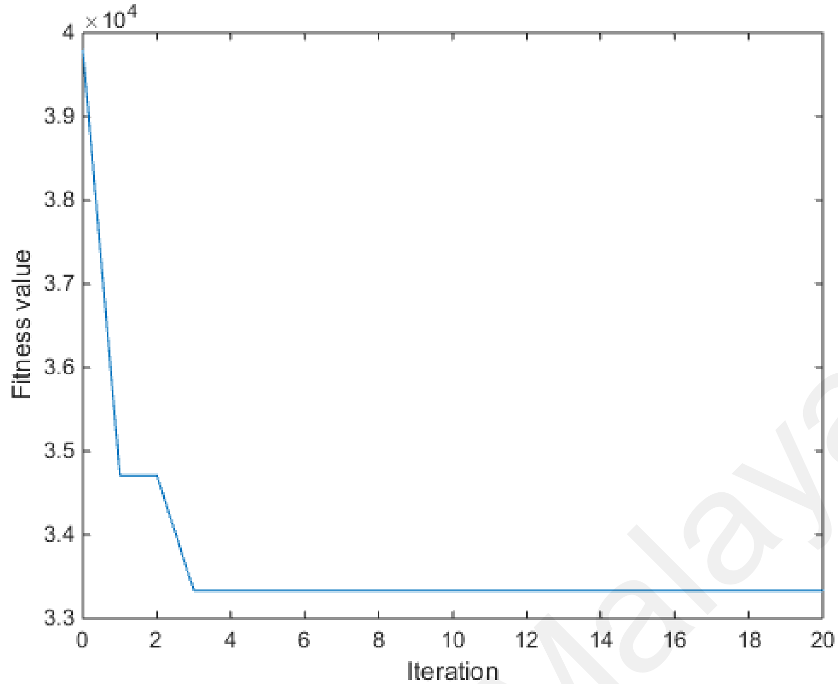

Figure 4.4: Convergence curve for GA for minimizing the total cost (at RM 33 333)

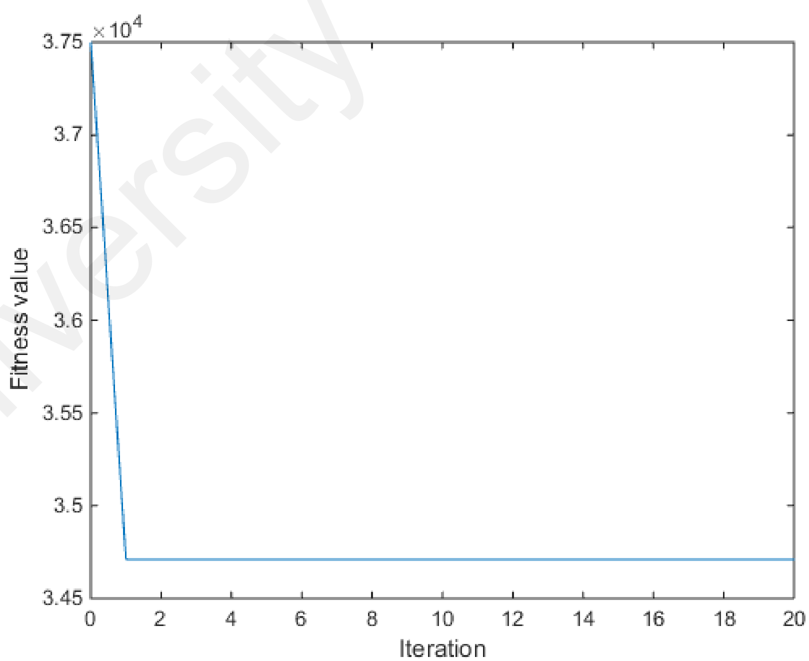

Figure 4.5: Convergence curve for GA for minimizing the total cost (at RM 34 710)

4.3.3.2 Minimizing the Total Voltage Drop

From Table 4.12, it can be seen that after 20 times of running the GA code with fitness function of minimizing the total voltage drop, the total voltage drop was minimized but the total cost was not minimized. Figure 4.6 shows the fastest time for the GA to converge. The GA method converges at second iteration.

Table 4.12: Result for GA for minimizing total voltage drop

No. of run	Total Voltage Drop (%)	Total Cost (RM)
1	0.5404	81 001
2	0.5404	81 001
3	0.5404	81 001
4	0.5404	81 001
5	0.5404	81 001
6	0.5404	81 001
7	0.5404	81 001
8	0.5404	81 001
9	0.5404	81 001

10	0.5404	81 001
11	0.5404	81 001
12	0.5404	81 001
13	0.5404	81 001
14	0.5404	81 001
15	0.5404	81 001
16	0.5404	81 001
17	0.5404	81 001
18	0.5404	81 001
19	0.5404	81 001
20	0.5404	81 001

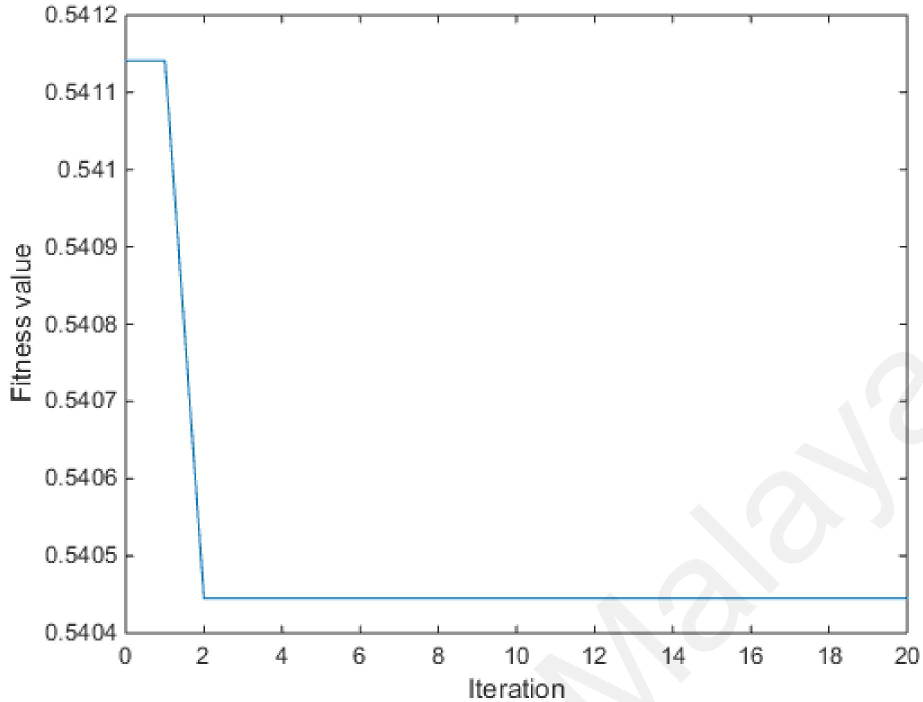

Figure 4.6: Convergence curve for GA for minimizing total voltage drop

4.3.3.3 Minimizing the Total Voltage Drop and total cost

From Table 4.13, it can be seen that after 20 times of running the GA code with fitness function of minimizing the total voltage drop and total cost, the total voltage drop and total cost were minimized. Figure 4.7 shows the fastest time for the GA to converge. The GA method converges at fist iteration.

Table 4.13: Result for GA for minimizing total voltage drop and total cost

No. of run	Total Voltage Drop (%)	Total Cost (RM)
1	0.8915	40 507

2	0.8915	40 507
3	0.8915	40 507
4	0.8915	40 507
5	0.8915	40 507
6	0.8915	40 507
7	0.8915	40 507
8	0.8915	40 507
9	0.8915	40 507
10	0.8915	40 507
11	0.8915	40 507
12	0.8915	40 507
13	0.8915	40 507
14	0.8915	40 507
15	0.8915	40 507
16	0.8915	40 507

17	0.8915	40 507
18	0.8915	40 507
19	0.8915	40 507
20	0.8915	40 507

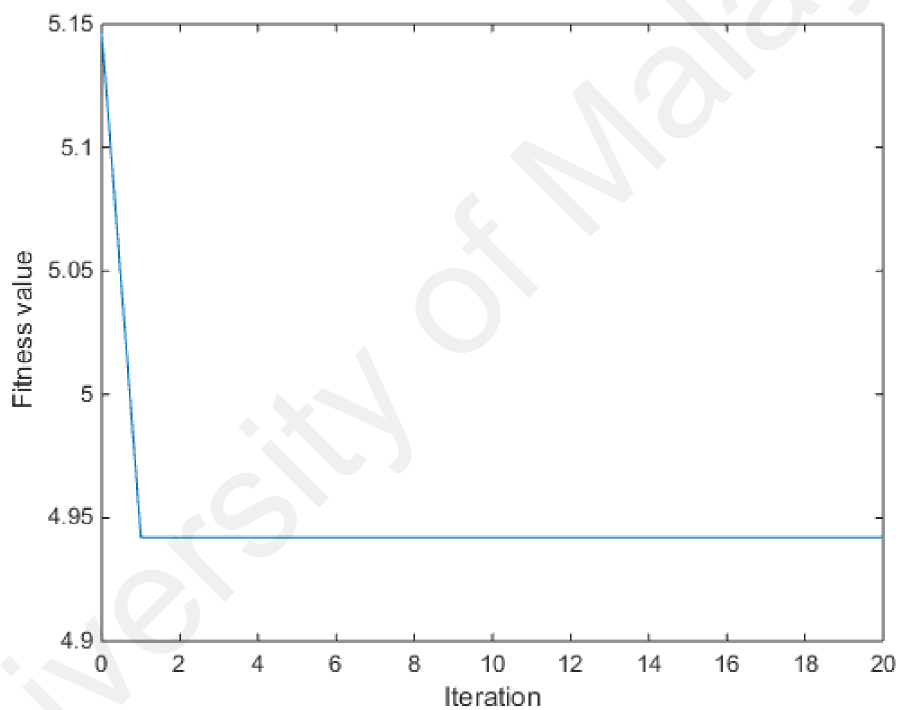

Figure 4.7: Convergence curve using GA for minimizing total voltage drop and total cost

4.4 Comparison of the results between PSO and GA

At the end of this study, after analysis was done, the results from these methods were compared with each other to determine the most suitable method to find the minimum total voltage drop and total cost. Also, the performance of GA and PSO are evaluates. Table 4.14 shows comparison of the results obtained using GA and PSO. From this table, the results from PSO and GA for minimizing the total cost only and total voltage drop only are the same. However, the results from PSO and GA for minimizing the total cost and total voltage drop at the same time yield different values. The total cost using PSO is higher than using GA but the total voltage drop using PSO is lower than GA. Referring to Tables 4.12 and Table 4.13, GA yields consistent results throughout different runs. Hence, in this case, GA is more suitable than PSO in finding the lowest total voltage drop and total cost when designing an electrical system in a building.

Table 4.14: Comparison of the results obtained using GA and PSO

Fitness function	**PSO**		**GA**	
	Total cost (RM)	**Total voltage drop (%)**	**Total cost (RM)**	**Total voltage drop (%)**
Minimizing Total Cost only	33 333	2.3945	33 333	2.3945
Minimizing Total Voltage Drop only	81 001	0.5404	81 001	0.5404
Minimizing Total Voltage Drop and Total Cost	43 975	0.7373	40 507	0.8915

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

In this work, to achieve lower total cost and total voltage drop, the optimized electrical wiring design based on the customers' requirements has been successfully proposed using particle swarm optimisation (PSO) and genetic algorithm (GA). The fitness function used was minimizing the total cost and total voltage drop of the electrical wiring system. Comparison between the optimisation methods and conventional methods show that the total cost and total voltage drop are lower when using optimisation methods. Comparison between the results using PSO and GA shows that both methods yield the same total cost and total voltage drop but GA yields consistent results compared to PSO. Therefore, GA is more suitable than PSO in finding the lowest total voltage drop and total cost when designing an electrical system in a building.

5.2 Recommendation for Future Work

Recommendations for future work are as follows:

1. Applied other optimisation methods such as Evolutionary Programming, Dynamic Optimization and others.
2. Enhance the performance of the system design by applying the other parameters value.
3. Consider different material applied to the system in electrical wiring design of a building.

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APPENDIX A

PROJECT DONE ON SITE

(a) Cable used as an outgoing from switchgear

(b) Combination of cable and busduct in Electrical riser

APPENDIX B

Schematic diagram of a system using cables application

APPENDIX C

Schematic diagram of a system using bus duct application

APPENDIX D

Schematic diagram of a system using cable and bus duct application