A Decade of Soft Computing Approaches in Power System Investment Planning

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Abstract. This paper opens up an issue regarding to power system investment planning. In order to obtain a sustainable electricity supply, the power outage should be minimized. Maintenance cost plays as an essential element in investment planning, therefore misdirect investment should be avoided. Since soft computing can solved this problem, this paper offers a review in solving investment planning problem through such approaches. The main objective of this paper is to examine the concept and findings by the researchers in power system investment planning problem. Besides, this paper will highlight the most relevant contributions and limitations that can be improve in the other research. Finally, this paper will be pointed out some trends in power system investment planning problem.

1. Introduction

Electricity demand has risen as a result of rapid economic growth and a steady rise in the world's population [1]. The total generating capacity in Peninsular Malaysia is 12,013.4 MW with 9.2 million users in 2016, according to the TNB Integrated Annual Report [2]. It is estimated that global energy consumption will increase by over 50% before 2030 if the current global energy consumption trend continues [3,4]. As demand continues to grow, meticulous planning should be given to improve the supply of power to customers.

The planning of the power system is described as the process of developing a minimum cost strategy for the long-term expansion of the generation, transmission and distribution systems in such a way that it is necessary to deliver the load forecast within the technological, economic and political constraints [5]. Since conventional energy planning approaches are likely to produce outcomes that may be unacceptable in vulnerable and conflict-prone countries, the risks of violence and disruption or substantial delays and cancellations in the construction of infrastructure are common in these countries. Thus, the inherent uncertainties must be specifically resolved by least-cost planning methods. While there are various statistical methods for dealing with decision-making under uncertainty, few of them have been applied and adapted to these circumstances in the planning of power systems [6].
For a stable and sustainable supply of electricity, the efficient operation and planning of power systems is becoming more relevant [7,8]. Optimization in the electric power system plays a critical and dominant role. Power system optimization problems are diversified and can be classified in terms of the characteristics of the objective function and form of constraint [9]. Data on insurance claims, as recorded in the National Fire Protection Association (NFPA) 70B maintenance standards [10,11], demonstrate that generally 50% of the costs associated with electrical failures could have been prevented by regular maintenance. Furthermore, a study published in the IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems [12] indicates that 49% of the failures of a poorly maintained system are due to lack of maintenance. Maintenance costs are a large portion of the issue with investment planning. Thus, to mitigate misdirected investments, an effective tool is required. In actual circumstances, investment planning issues are complex and difficult to solve non-linear programming problems. Therefore, soft computing is a legitimate and persuasive approach to solving the problem.

This research presents critical and comprehensive reviews of soft computing approaches in power system investment planning. Section 2 presents brief introduction of soft computing approaches; section 3 demonstrates comprehensive and critical reviews based on existing methods. Section 4 discuss in detail on methodological contribution and some limitations. This section also depicts experimental validation by the previous research, observation and discussion. Finally, concluding remarks and future trends are presented in section 5.

2. Brief introduction of soft computing approaches

According to [13], a new approach for Machine Intelligence was proposed which separated hard computing technique based Artificial Intelligence (AI) from soft computing technique based Computational Intelligence (CI). Theoretically, hard computing is subject to analyse and design the system and physical process which consists the quality, formality and category. It is based on binary logic, crisp systems, numerical analysis, probability theory, differential equations, functional analysis, mathematical programming, and approximation theory and crisp software. Soft computing, meanwhile, is used to analyse and design intelligent systems. Although imprecision and uncertainty are undesirable properties in hard computing, the tolerance to imprecision and uncertainty is taken into account in order to achieve a lower cost tractability solution and a high Machine Intelligence Quotient (MIQ).

Soft computing is the state-of-the-art approach to AI and it has showed an excellent performance in solving the combined optimization problems [14]. In comparison to conventional computing, soft computing deals with approximate models and offers solutions to complex real-life issues. Kaynak et al. [15] argued that soft computing should be viewed as the foundation of real machine intelligence rather than hard computing as soft computing is a consortium of methodologies providing a foundation for the conception and design of intelligent systems, aimed at a formalization of the remarkable human ability to make rational decision in an uncertain and imprecise environment. The guiding principle of soft computing is exploiting the tolerance for imprecision, uncertainty and partial truth to achieve tractability, robustness, low solution cost and good interaction with reality.

Soft computing is tolerant of imprecision, ambiguity, partial truth, and approximations, unlike hard computing. The role model for soft computing, in effect, is the human mind [16]. This is where soft computing approaches score over the conventional hard computing approaches. Soft computing is based on techniques such as Particle Swarm Optimization (PSO), Fuzzy Logic (FL), Genetic Algorithms (GA), Artificial Neural Networks (ANN), machine learning, and expert systems [17–21]. Although soft computing theory and techniques were first introduced in 1980s [18], it has now become a major research in various area especially in engineering. In many domestic, commercial and industrial applications, soft computing methods are now being successfully used [22–26]. It is clear that the techniques and application areas of soft computing will continue to grow with the improvement of low-
cost and very high-performance digital processors and the decline in the cost of memory chips [19]. Figure 1 shows a better understanding about soft computing approach.

Based on the explanation regarding power system planning and soft computing approach, thus, this paper will review on the application of soft computing approach to power system planning over a decade. The objective of this review is to examine the concept and findings by the researchers in power system investment planning. Besides, this paper will highlight the most relevant contributions and limitations in terms of investment planning that can be improved in the other research. Finally, some trending approach in power system problems are pointed out.

![Figure 1. AI versus CI](image)

3. Soft Computing Approaches applied into Power System Investment Planning Problem

Electricity plays a vital role in daily human life. Basically, the electric power system provides the final users of the load with a means of generating, transmitting and distributing energy in the form of electric current. Four fundamental elements or subsystems of the power system are created by generation, transmission, distribution and load. Every section in power system has its important in power system. Figure 2 shows the overall process to supply electricity.
According to Figure 2, the beginning step is generation the electricity. Electric power is generated in a power station at a certain voltage. The voltage is then step up by using power transformer to a very high voltage in order to prevent the losses during transmission process. Then, the voltage is transmitted to commercial and industrial business consumer via transmission lines. Next, the voltage is stepped down in the distribution stations and then will be distributed to residential consumers. Each section in power system plays an important role, thus, a well planning expansion is one of essential element that should be done. In this paper, only covered a review on distribution system expansion planning (DSEP).

In the 21st century, the planning of distribution systems has been a very hot topic [30]. DSEP deals with the constantly growing demand for loads [31]. The phases of the plan and total time period in DSEP; the methods of handling distribution feeders and substations in terms of cost representation, location and sizing issues; considerations of radiality and voltage drop; and the mathematical programming techniques used to solve this issue [32,33]. In a heuristic selection method of plan choices, beginning from the terminal year and propagating backwards to the initial year it uses a basic economic criteria, the ‘cost-benefit analysis,’ to arrive at a plan solution [34].

According to Ganguly et al. [35], DP is a convenient approach to solve DSEP since it has better iterative approach and applicable for planning. The mathematical model for multi-stage distribution substation planning has been proposed by Yanan et al. [36] to decide simultaneously on the substation planning scheme at each stage. HNN was employed in every step to calculate the planning scheme of each substation. MC is used by Davidov and Pantos in [20] and mentioned that this method can help investor to invest more cost-efficiency investment in power system. Akbari et al. as in [37] proved that MC can assist to minimize the sum of investment costs and operation costs.

In [38], Tafreshi et al. suggested GA to calculate the optimal system configuration that can achieve the loss of power supply probability (LPSP) with minimum energy cost (COE) required for customers, while Falaghi [39] used the same approach to solve multi-stage DSEP that solved the installation of substations, feeders and DG suitable for capacity expansion. Another researcher used the same approach to solve DSEP [40–48]. Nazar et al. and Naderi et al. in [40, 44, 45] able to minimize the investment and operational cost and maximizing the reliability of the system at the same time meanwhile Celli et al. [41] proposed GA with DP to define the optimal placement, rating and control strategy of distributed
storage system which minimizing overall operation cost. In order to quantify the minimum cost for operating a distribution company as well as it services the same demand with the actual company, Jimenez et al. [42] found that GA is able to solve the problem as the proposed approach can deal with large-size distribution system. Besides, Kong et al. [43] discovered that GA is a practicable solution for DSEP problem as it can help the planning process of open-loop medium voltage (MV). GA also help to plan the medium and long term DSEP as mentioned by Taroco et al. in [47] while another founding by Carrano et al. in [48] discovered that GA can solve allocation of limited financial resources.

Pinto et al. [49] used PSO to solve DSEP problem since this approach can provide the best investment planning with increasing profit. According to Wishart et al., [50] PSO can be used to easier the power system planning, meanwhile, Asadi et al., Abd-el-motalab and Alvarado as in [51, 52] lower the investment cost and risk. Malee et al. [31] discovered that PSO able to solve DSEP since the simulation result satisfies the voltage limit, DG, feeder transfer and substations capacity and reduce the DSEP as well as losses. Besides that, ACO also has been used in solving DSEP as proposed by Zhu et al. in [54]. This approach is found have the ability to solve the optimal design of distribution network in distribution system.

The Artificial Immune System (AIS), suggested by Souza et al. and Junjie et al. [55, 56], is another method that consists of the capacity to overcome DSEP. AIS has developed a systematic set of solutions [55] that are capable of solving the DSEP problem in smart grid planning and achieving the optimal DG solution [56]. MILP that solved by SA is proposed by Popovic et al. [57] to solve DSEP problem while Parada et al. [58] used SA and Tabu Search to solve Distribution Tree Problem (DST) which to find the deviation between long-term planning and optimal topology for actual condition of networks. Tabu Search is the used without combination with another soft computing approaches as proposed by Ramirez-Rasado et al. and Cossi et al. [59, 60].

Table 3 shows the summary of approaches in soft computing to solve DSEP. The selected soft computing approaches are mentioned in this table with the references number of publications. GA and PSO are mainly used by researchers to solve DSEP problem followed by Tabu Search.

| Problem | Approach | References |
|---------|----------|------------|
| -Deals with continuous increasing load demand. | PSO | [31,49–5] |
| -Treating distribution feeder and substations in terms of cost, location, sizing and voltage drop consideration. | DP | [35] |
| | HNN | [36] |
| | GA | [38–48] |
| | ACO | [54, 61] |
| | AIS | [55, 56] |
| | MILP/SA | [57] |
| | Tabu Search | [58–60] |

4. Methodological Contribution and Limitation
The previous section has shown the variety types of soft computing approach in solving power system investment planning problem. In this section, the contribution for each approach will be discussed further. It has been found that the operation cost, investment cost, annualized cost and planning cost can be reduced regarding to the findings in [38, 39]. Results obtained according to [36] indicated that the network line losses is decreased with minimum power distance.

In order to decide best expansion by having a quality investment strategy, [61] have proposed the affordable solution, meanwhile several approaches offered a possible investment and more economically [20]. ANN [62], double layered Boltzmann Machine [63] and structural learning of ANN
[64] provided a balance investment and risk to investor while DLNN in [65] offered a maximum profit for investor. In the other hand, a finding by [66] proved a solution for cost allocation.

Particular attention is paid to produce a fast convergence and low the computational time [29]. It was then followed by improving overall system operation by having a stable operation. [49] described that PSO can be used to produce a good solution in terms of provided a market player that enough with participant in power system investment.

Other findings are stated in [67] which solved complex optimization problem meanwhile [67] produced optimal solution. [29] proved that two-stage stochastic and three level Adaptive Robust Optimization can overcome problem size limitations and computational deficiency. [68] suggested a good performance model by using NBI with FL while another approach that produced a satisfy solution in predicting load have been expressed.

The effectiveness of solution was provided in [50, 69] meanwhile high efficiency solution was demonstrated. In order to obtain accurate and reliable solutions, several authors have illustrated the results in [39, 50, 6] while the flexibility was demonstrated in [52]. There are several soft computing approaches that provide a coordination for DG unit placement [51] and helping in transmission and generation sizing process.

However, there are several drawbacks that have been pointed out. [70] was not able to demonstrated the convergence efficiency while [71] needed more computational effort to produce the solution. [72] at the same time found that the approach used caused more complexity of the system and found that the approach used increase the cost as it has to increase the wind turbine output power. Another limitation was found in [49] and still have to be improved where the proposed approach not addressing the minimum operation cost and risk management. Other than that, [73] may be not practical as the approach is not suitable for huge system and not relevant for other different problem such as static problem and need several updates to solve multi objective problem.

5. Conclusion and future trends
This paper was concerned to find out and reviewed all the possible approaches to solve expansion planning problem in power system. According to the publications by previous researchers that have been reviewed, the number of publications that related in solving expansion problem over a decade is increasing after 2010. Based on the methodological contributions, soft computing approaches have better performance compared to traditional method. The great used in soft computing over a decade is due to the nature of real data which imperfect, noisy, inconsistent and consists of several complexity where the uses of mathematical model can be impractical or even impossible due to the lack of mechanism that can determined a phenomenon under consideration. The use of soft computing approaches demonstrated that the operation cost can be minimize and useful for power system expansion planning problem. These tools also contributed in improving the robustness of the decisions at different level of system’s life cycle. The approaches are applicable since it can enhance the efficiency and effectiveness of operation and maintenance of power system expansion planning through improving the availability level. Since all the possible approaches in solving DSEP have been demonstrated, thus a sustainable, secure and competitive energy could be well-prepared for future use. This review paper was conducted to provide the state-of-art in power system expansion planning area which can be guidance for future research works.

6. References
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