OPTIMAL UNDER VOLTAGE LOAD SHEDDING BASED ON STABILITY INDEX BY USING ARTIFICIAL NEURAL NETWORK

SHARMAN A/L SUNDARAJOO

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I dedicate this project report to my beloved supervisor, family and friends

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ABSTRACT

Power system is exceptionally sensitive at the generation and consumer side. Inconsistent power requirement under general power production environment may cause power system to approach breakdown or power outages. Load shedding is deliberated as the final choice from the numerous techniques which have been achieved to prevent voltage breakdown. Various studies have been led on this part of the issue. Still, there are possibilities for other ways through optimization of the load shedding. Consequently, the primary reason for this work is to come up with an optimal undervoltage load shedding strategy. Voltage stability is one of the significant worries in functional and preparation of present-day power system. Nevertheless, to obtain the lowest amount to be shed in order to avoid voltage instability, optimization is required. An algorithm was developed to shed the optimal load by considering the load priority whereby the load with least priority will be shed first. The algorithm is working in one step to shed the load. The developed algorithm was tested on IEEE 33-Bus and IEEE 69-Bus radial distribution systems. The results show the equal accuracy of the application of the developed algorithm. In this project, a powerful technique is exhibited for evaluating the optimal amount of load to be shed in a radial distribution system by using artificial neural network. The results of these test cases confirm that 6.57% of bus voltage is increased at the weakest bus in the IEEE 33-Bus system and 10.23% of bus voltage is increased at the weakest bus in the IEEE 69-Bus system. This optimal load shedding algorithm does not over shed or under shed the load. Other achievement includes reduction in load shedding steps. For each test case, the complete load shedding was achieved in 1 step only and the amount of load shed is suitable in each test case respectively. In this project, 29.4% of load is curtailed to stabilize the system which is less compared to other works where about 30% of load is shed to stabilize the system.

ABSTRAK

Sistem kuasa sangat sensitif pada generasi dan pengguna. Keperluan kuasa yang tidak konsisten di bawah persekitaran pengeluaran kuasa umum boleh menyebabkan sistem kuasa mendekati kerosakan atau gangguan kuasa. Pengurangan beban dibincangkan sebagai pilihan terakhir dari banyak teknik yang telah dicapai untuk mencegah pecahan voltan. Pelbagai kajian telah diketengahkan di bahagian ini. Walau bagaimanapun, terdapat kemungkinan untuk cara lain melalui pengoptimuman penguranggan beban. Akibatnya, sebab utama kerja ini adalah untuk menghasilkan strategi menumpahkan beban undervoltatif yang optimum. Kestabilan voltan adalah salah satu kebimbangan penting dalam fungsi dan penyediaan sistem kuasa masa kini. Walau bagaimanapun, untuk mendapatkan jumlah yang paling rendah untuk diturunkan untuk mengelakkan ketidakstabilan voltan, pengoptimuman diperlukan. Algoritma telah dibangunkan untuk mengurangkan beban optimum dengan mempertimbangkan keutamaan beban di mana beban dengan keutamaan paling rendah akan dikurangkan terlebih dahulu. Algoritma ini berfungsi dalam satu langkah untuk menumpahkan beban. Algoritma yang dibangunkan telah diuji pada sistem IEEE 33-Bus dan IEEE 69-Bus. Hasilnya menunjukkan ketepatan yang sama penerapan algoritma yang dibangunkan. Dalam projek ini, teknik yang kuat dipamerkan untuk menilai jumlah beban yang optimum untuk dikurangkan dalam sistem dengan menggunakan rangkaian saraf buatan. Keputusan kes ujian ini mengesahkan bahawa 6.57% voltan dinaikkan pada bas yang paling lemah dalam sistem IEEE 33-Bus dan 10.23% voltan dinaikkan pada bas paling lemah dalam sistem IEEE 69-Bus. Algoritma ini menumpu yang optimum dan tidak melebihi susut atau di bawah menguranggkan beban. Pencapaian lain termasuk pengurangan langkah utk mengggurangkan beban. Setiap kes ujian telah dicapai dalam 1 langkah sahaja dan jumlah gudang beban sesuai di setiap kes ujian. Dalam projek ini, 29.4% beban dikurangkan untuk menstabilkan sistem yang lemah berbanding dengan kerja lain di mana kira-kira 30% beban diturunkan untuk menstabilkan sistem.

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LIST OF SYMBOLS AND ABBREVIATIONS

θ	Teta
Degree	Bus Angle
LSI	Line Stability Index
VCPI	Voltage Collapse Prediction Index
UFLS	Under Frequency Load Shedding
UVLS	Under Voltage Load Shedding
ROCOF	Rate of Change of Frequency
SI	Stability Index
LS	Load Shedding
CV	Control Variable
VSM	Voltage Stability Margin
AC	Alternating Current
ANN	Artificial Neural Networks
SI	Stability Index
LVSI	Line Voltage Stability Index
FFBPNN	Feed Forward Back Propagation Neural Network
FVSI	Fast Voltage Stability Index
LFA	Load Flow Analysis

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter is arranged as follows. The background of the project is analysed in section 1.2. In section 1.3, the problem statement for organizing the project is reviewed. The primary objective and set objectives of this project are established in section 1.4. The scope of this project is stated in section 1.5. The project summary is illustrated in section 1.6. Summary for Chapter 1 is explained in section 1.7.

1.2 Background of the project

Several large-scale blackouts related to the voltage stability have happened in Malaysia and other countries all over the world. The major blackouts occurred in the world took place in many different years. The Turkey blackout on March 21, 2015, affected 89.8 percentage of population in the country which is approximately 70 million people. Roughly 32 GW of load was interrupted. The duration of this blackout is more than 7 hours [1]. According to the reports [2, 3], on July 30, 2012, a highly severe blackout happened and remained from 2 to 8 hours in the Indian power network. The blackout affected over 620 million people in the country. This caused the estimated values of 32 GW of scarcity in the generation. Another disturbance took place on July 31, 2012 in India as a result of deficiency in the generation with greater demand. In this power outage, approximately 48 GW capacity was affected. Due to the blackout, roughly 700 million people in the country were affected.

On February 4, 2011, in Brazil, nearly 40 million of people were affected due to a serious power outage. This blackout affected roughly 40 million of customers. About 8.9 GW of loads were disrupted. This blackout endured for almost 3 hours. On April 26, 2007, a severe power outage took place in Florida. Approximately, 41 million people were left without power service. Estimated value of 3.65 GW of loads were affected. This event persisted for 3 hours [1].

Meanwhile, in the history of Union for the Coordination of the Transmission of Electricity (UCTE), the Europe blackout which took place on November 4, 2006 is the most serious blackout. Almost 15 million people in the Europe were affected during the disturbance. Approximately, 14.5 GW of loads were disrupted. As a consequence, the loads were not provided with power roughly for 30 minutes to 90 minutes [4].

On May 17, 2005, another major power outage began in the Vietnamese power grid and affected electricity disturbance about 1074MW lost [5]. On July 12, 2004, a massive blackout due to voltage instability event took place in all areas South of Athens [6]. On November 8, 2003, a major blackout occurred in Libya and had affected 74 percent of the customer's load [7]. On August 3, 1996, a major blackout in Peninsular Malaysia took place. All power plant in Peninsular Malaysia failed due to a transmission line tripping in Paka, Terengganu. This resulted a massive power outage in Peninsular Malaysia which lasted nearly six hours [8, 9]. On July 23, 1987, a massive power outage took place in the Tokyo city caused by voltage instability [10].

There are various causes for a distribution system to face voltage instability issues. Overhead distribution components like pole mounted transformers, overhead line conductors, switches, pole mounted capacitors and other is supported by the distribution poles. Tumbling trees, lightning, strong wind, flying wreckage and defect because of intense atmospheric conditions stimulate power failures and may result distribution poles ending in power blackouts, network damage and expensive restoration expenditure [11].

Distribution system is nearest to the users. Therefore, they need strong consideration. Additionally, with advancement of technology, distribution network deals with the hypersensitive customers such as industrial, hospital and digital loads to electricity with greater security has been raised. Furthermore, regular customers wish minimum quantity of blackouts [12].

1.3 Problem statement

The capability of power network to sustain steady state voltage at every bus ahead and afterwards the power system exposed to emergency is defined as voltage stability. A power network is termed voltage unsteady when the power network failed to manage the emergency and incapable to retain steady state bus voltage after emergency occurred [13].

Several major blackouts all over the world have shown that voltage instability is one of the reasons of the blackout. Various existing solutions such as building new transmission and distribution systems, building new power plants, and also improving controlling structure of current power plant network have been introduced. However, all these existing solutions were demanding large initial rate, huge resources and necessity of expert labor force [14].

As a result, most power networks are forced to function to their stability limit. Thus, few regions of the power system may force to operate at stress circumstances. This will cause great possibility for voltage instability. Therefore, it is vital to enhance the power network balance and strength in the present power network. For that, there are various methods to prevent voltage instability and under voltage load shedding (UVLS) is the final step to stop voltage collapse from happening in the power system [15, 16]. This can be done by removing buses with instable voltage. Still, the location of the load to be curtail is significant to prevent over or under voltage to occur [17].

Voltage stability analysis is really crucial in consideration of strong and stable power network. Voltage stability analysis can be carried out by two ways. First method is by using static approach and the second method is by using dynamic approaches. There are some techniques of static voltage stability analysis such as minimum singular value method, P-V curve method, continuation power flow method, and V-Q curve modal analysis method [18]. Besides that, voltage stability indices are broadly utilized for determining sluggish bus in the system [16]. Some of the stability indices are L-Index, Stability Index (SI), Line Stability Index (LSI), Voltage Collapse Prediction Index (VCPI), and Line Voltage Stability Index (LVSI) [19].

A combination of processing units based on neurons that are linked to each other to attain performance very much alike human's performance when figuring out obstacle could be described as Artificial Neural Network (ANN) [20]. Presently, utilization of ANN to the voltage stability problem has gained rising interest. ANN has the ability to solve long-established problems regarding power system where conventional methods have struggled. Moreover, ANN has the capability to carry out parallel processing of data with immense precision and quick feedback. ANN [21].

Therefore, in this project, an optimal load shedding (LS) algorithm is developed by using ANN.

1.4 Objectives of project

The primary objective of this project is to produce an optimal LS scheme in distribution system. The following set objectives will help to achieve the primary aim of this project:

a) To develop a LS algorithm by using SI and ANN in Matlab.

b) To test the developed LS algorithm on 33-bus and 69-bus radial distribution test system.

1.5 Scope of Project

Numerous voltage stability indices can be implemented to evaluate the stability condition of a power network. In this project, the purpose for concentrating on the SI is because it is fast compared to the other voltage stability indices. In addition, it can accurately validate the weak bus in the distribution network. Consequently, the scope is limited into focusing on SI only.

This work will only consider one major technical issue in LS scheme-based SI and the load selectivity for LS using ANN. The proposed scheme will be tried on the IEEE 33-bus and IEEE 69-bus radial distribution system by using MATLAB.

1.6 Project outline

This project justifies the accomplishment of SI with ANN to perform LS in the distribution system. The literature review of the related works is illustrated in Chapter 2. The literature review of each proposed algorithm and techniques are studied as well. Chapter 3 presents the procedure and process for the LS. Chapter 4 demonstrates results and discussion for the applied technique for LS based on SI and ANN for different types of cases. The conclusion and future works on the work are discussed in Chapter 5.

1.7 Summary

This chapter examine regarding the preface for the complete project. The background of project linked with the work was interpreted in the section 1.2. In section 1.2 it is reviewed some of the major blackouts occurred around the world in various years. The problem statement for this project were recorded in section 1.3. This section compiled the relation between voltage stability and blackouts. The main motive of discussing the events of blackouts was to signify that the number of blackouts happened before was severe. Therefore, corrective behaviour should be taken to curtail the number of blackouts. The aim of the project was defined in section 1.4. The objective for this project was to develop an algorithm using SI and ANN for LS. The scope of work for the project was exemplified in section 1.5. The short review for the scope of work were regarding the furnished SI, the applied software in this work, the technique used in this project for LS and the distribution test systems that being applied in the project. The organisation of the project was classified in section 1.6. Generally, this project comprised five chapters.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter consists of overview followed by section 2.2 to clarify the concept about electric power system. Concurrently, section 2.3 will review about the distribution system. The power system stability is presented in section 2.4. Brief about LS followed by UVLS is reviewed in section 2.5 and section 2.6 respectively. The definition of voltage stability is explained in section 2.7. The analysis of the voltage stability index is explained in section 2.8. The two distinct types of voltage stability indices are reviewed in section 2.9 and 2.10 respectively. The ANN methods in voltage stability monitoring is reviewed in section 2.11. The summary for Chapter 2 is reviewed in section 2.12.

2.2 Electric power system

Generally, a generating, a transmission, and a distribution system is the description of electric power system [22]. The primary elements of an electric power system.is the generation, transmission, and distribution systems. Generation system and distribution system are linked by transmission lines.

Usually, for the transportation of large power, the transmission lines are involved. Otherwise, distribution network is principally in charge for transmitting this power for smaller voltage network users [23].

Today, all around the world, there are various residential, commercial, and industrial users of electrical power systems. To meet this wide need for electrical power, power utilities performs in association to generate huge capacity of electrical power. This large amount of electrical power is provided by generating stations to be transported to the users [24].

Typically, the generating stations are situated away from the township and metropolitan where the electrical power is requested. For that reason, there is large system of conductors between the power plant and the users. This system is widely classified into two regions which is transmission and distribution [25].

Electrical energy can be generated by several methods e.g. from chemical reactions, heat, light, or mechanical energy. However, large amount electrical energy is generated by power plants situated throughout the world is by converting the energy created by burning coal, oil, or natural gas, by falling water, or by nuclear reactions into electrical energy. In the case of hydroelectrical plants, electrical generators are driven by steam or gas turbines, or by hydraulic turbines [26].

The flow of electricity from the power plan to the user is known an electric power system. It includes the subsequent vital elements:

a) Generating plant

b) Transmission system

c) Distribution system

All these vital systems are linked with the aid of conductors and many step-up and step-down transformers. A common transmission and distribution system are shown in Figure 2.1.

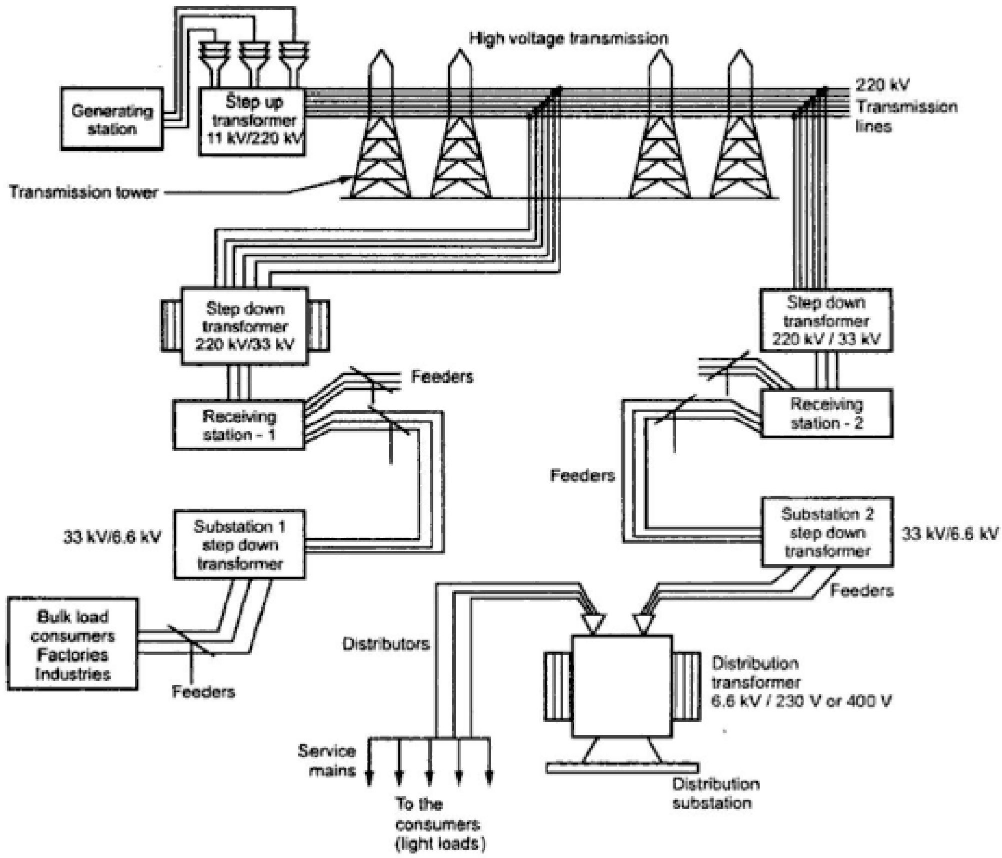

Figure 2.1: Typical components of a power system [25].

2.3 Distribution system

Previously, the distribution system was predicted to be approximately balanced in main expenses to the generation ability. Also, distribution system presented over 80 percent of the entire power system expenditure [22]. Almost all of the electricity is transported from the transmission, or sub transmission system to high voltage distribution system and medium-voltage distribution system. This is done to deliver electrical energy precisely to the user. The distribution network is commonly linked in a radial arrangement as disputed to the mesh arrangement utilized in the transmission network.

Big buyers can be provided from a weakly coupled or weakly meshed distribution network. Otherwise, huge consumers may be provided from two radial feeders with a probability of automatic switching between feeders in case of a power outage. In addition, on-site power production may be an option for some industrial consumers. Basically, electrical energy is converted to a small voltage and delivered straight to customers. Normally, distribution systems have been passive. This is due to the small generation connected to them. However, nowadays, the swift advancement in distributed and renewable production has replaced that illustration.

Power flows in distribution systems may not anymore be in one direction, which is from the transmission network straight to the end users. In various occasions, the stream may be in oppose way when the wind is powerful. In addition, distribution systems are flattering exclusive exporters of power. However, that phenomena have introduced many technical threats to the protection systems, voltage drops, congestion management and many more. Usually, roughly 8–10% of the electricity emerging at the generator terminals will be lost on its way to the users in the transmission and distribution level [26].

The transmission and distribution system combine all the power stations into one supplying network. Then, they transport and delivers electrical energy to respective customers. The fundamental component of the system are the overhead power lines, underground cables, transformers and substations. Supplementary components are the series reactors, shunt reactors and compensators, switching components, metering equipment and protection elements [22, 26].

Distribution systems normally functions at lesser voltages than the transmission network. The voltage standards used, differs by country and also differs by areas in a country. It may be fully different, partially due to the manner the network has advanced. Classically, various component of a system can fit to distinct private companies each of which would have pursue its own standardization measures. For instance, there are various standard distribution voltages in Malaysia. In Malaysia, the distribution voltages are 6.6 kV, 11 kV, 22 kV, 33 kV and 66 kV [26, 27].

2.4 Power system stability

Power system stability signifies that its capability to restore to ordinary or usual functionality after having exposed to some disruptions [23]. Three quantities are crucial for electrical system function ability:

a) power angles, δ

b) frequency f

c) nodal voltage magnitudes V

These quantities are exclusively decisive from the perspective of characterizing and analysing power system stability. Thus, power system stability can be classified into:

a) rotor angle stability

b) frequency stability

c) voltage stability.

Power system stability rely on both the beginning states and the capacity of a disturbance due to its nonlinearity. As a consequent, angle and voltage stability can be classified into small- and large-disturbance stability as illustrated in Figure 2.2.

REFERENCES

[1] O. P. Veloza and F. Santamaria, "Analysis of major blackouts from 2003 to 2015: Classification of incidents and review of main causes," *The Electricity Journal*, vol. 29, no. 7, pp. 42–49, 2016.

[2] Y. K. Wu, S. M. Chang, and Y. L. Hu, "Literature Review of Power System Blackouts," *Energy Procedia*, vol. 141, pp. 428–431, 2017.

[3] L. L. Lai, D. Ramasubramanian, H. T. Zhang, F. Y. Xu, S. Mishra, and C. S. Lai, "Lessons Learned from July 2012 Indian Blackout," *9th IET International Conference on Advances in Power System Control, Operation and Management (APSCOM 2012)*, 2012.

[4] X.Chen, C.Deng, Y.Chen, and C.Li "Blackout Prevention: Anatomy of Blackout in Europe," pp. 928–932, 2007.

[5] V. T. Dinh and H. H. Le, "Vietnamese 500kV power system and recent blackouts," *2008 IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century*, 2008.

[6] C. D. Vournas, V. C. Nikolaidis, and A. Tassoulis, "Experience from the Athens blackout of July 12, 2004," *2005 IEEE Russia Power Tech*, 2005.

[7] M. El-Werfelli, R. Dunn, M. Redfern, and J. Brooks, "Analysis of the national 8th November 2003 Libyan blackout," *2008 43rd International Universities Power Engineering Conference*, 2008.

[8] *Akta Suruhanjaya Tenaga 2001 (Akta 610) ; & Energy Commission Act 2001 (Act 610): hingga 20hb Julai 2001*. Petaling Jaya, Selangor Darul Ehsan: International Law Book Services, 2001.

[9] T. B. Smith, "Privatising electric power in Malaysia and Thailand: politics and infrastructure development policy," *Public Administration and Development*, vol. 23, no. 3, pp. 273–283, 2003.

[10] T. Ohno and S. Imai, "The 1987 Tokyo Blackout," 2006 IEEE PES Power Systems Conference and Exposition, 2006

[11] R. Bhat and A. Meliopoulos, "Probability of distribution network pole failures under extreme weather conditions," *2016 Clemson University Power Systems Conference (PSC)*, 2016.

[12] I. Zabet and M. Montazeri, "Implementing cooperative agent-based protection and outage management system for power distribution network control," *2010 4th International Power Engineering and Optimization Conference (PEOCO)*, 2010.

[13] T. G. Tella, S. S. Sitati, and G. N. Nvakoe, "Voltage Stability Assessment on Ethiopian 230 KV Transmission Network Using Modified Voltage Stability Indices," *2018 IEEE PES/IAS PowerAfrica*, 2018.

[15] M. H. A. Hamid, H. Hashim, H. A. A. Rashid, and I. Z. Abidin, "Under voltage load shedding using voltage stability indices," *2014 IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA)*, 2014.

[16] P. Rajalakshmi and M. Rathinakumar, "A comparison of transmission line voltage stability indices," *2016 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)*, 2016.

[17] N. Yusof, H. Mokhlis, J. Laghari, M. Karimi, H. Illias, and N. Sapari, "Under-Voltage Load Shedding Scheme Based on Voltage Stability Index for Distribution Network," *3rd IET International Conference on Clean Energy and Technology (CEAT) 2014*, 2014.

[18] M. Chakravorty and S. Patra, "Voltage stability analysis using conventional methods," *2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES)*, 2016.

[19] K. Selvakumar, C. S. Boopathi, and M. S. Harsha, "Voltage Stability Assessment using Artificial Neural Networks," *Indian Journal of Science and Technology*, vol. 9, no. 38, 2016.

[20] K. S. Sajan, B. Tyagi, and V. Kumar, "Genetic algorithm based artificial neural network model for voltage stability monitoring," *2014 Eighteenth National Power Systems Conference (NPSC)*, 2014.

[21] M. M. Hamada, M. A. A. Wahab, and N. G. A. Hemdan, "Artificial Neural Network Modeling Technique for Voltage Stability Assessment of Radial Distribution Systems," *Proceedings of the 41st International Universities Power Engineering Conference*, 2006.

[22] Gönen Turan, *Electric power distribution system engineering*. Boca Raton: CRC Press, 2008.

[23] D. Das, *Electrical power systems*. New Delhi: New Age International (P) Ltd., Publishers, 2006.

[24] S. W. Fardo and D. R. Patrick, *Electrical power systems technology*. Lilburn, GA: Fairmont Press, 2009.

[25] U. A. Bakshi and V. U. Bakshi, *Protection of power system*. Pune, India: Technical Publications, 2010.

[26] J. Machowski, J. W. Bialek, and J. R. Bumby, *Power system dynamics stability and control*. Chichester: Wiley, 2012.

[27] "Map of Peninsular Malaysia," *The Development and Distribution of Deijiao Associations in Malaysia and Singapore*, pp. xi-xi, 1985.

[28] R. Faranda, A. Pievatolo, and E. Tironi, "Load Shedding: A New Proposal," *IEEE Transactions on Power Systems*, vol. 22, no. 4, pp. 2086–2093, 2007.

[29] B. Otomega and T. V. Cutsem, "Undervoltage Load Shedding Using Distributed Controllers," *IEEE Transactions on Power Systems*, vol. 22, no. 4, pp. 1898–1907, 2007.

[30] S., V.V., An Intelligent Load Shedding Approach to Enhance The Voltage Stability of Power System, 1991, University of washington.

[31] S. Hirodontis, H. Li, and P. Crossley, "Load shedding in a distribution network," *2009 International Conference on Sustainable Power Generation and Supply*, 2009.

[32] L. Sigrist, I. Egido, and L. Rouco, "Performance Analysis of UFLS Schemes of Small Isolated Power Systems," *IEEE Transactions on Power Systems*, vol. 27, no. 3, pp. 1673–1680, 2012.

[33] H. Seyedi and M. Sanaye-Pasand, "New centralised adaptive load-shedding algorithms to mitigate power system blackouts," *IET Generation, Transmission & Distribution*, vol. 3, no. 1, pp. 99–114, 2009.

[34] Z. Ding, D. Cartes, and S. Srivastava, "New Load Shedding Scheme for Islanded Power Systems," *2006 IEEE/SMC International Conference on System of Systems Engineering*.

[35] "IEEE Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration."

[36] E. Thalassinakis and E. Dialynas, "A Monte-Carlo Simulation Method for Setting the Underfrequency Load Shedding Relays and Selecting the Spinning Reserve Policy in Autonomous Power Systems," *IEEE Transactions on Power Systems*, vol. 19, no. 4, pp. 2044–2052, 2004.

[37] B. Delfino, S. Massucco, A. Morini, P. Scalera, and F. Silvestro, "Implementation and comparison of different under frequency load-shedding schemes," *2001 Power Engineering Society Summer Meeting. Conference Proceedings (Cat. No.01CH37262)*, 2001.

[38] S. Ladhani and W. Rosehart, "Under voltage load shedding for voltage stability overview of concepts and principles," *IEEE Power Engineering Society General Meeting*, 2004.

[39] C. Taylor, "Concepts of undervoltage load shedding for voltage stability," *IEEE Transactions on Power Delivery*, vol. 7, no. 2, pp. 480–488, 1992.

[40] R. Balanathan, N. Pahalawaththa, U. Annakkage, and P. Sharp, "Undervoltage load shedding to avoid voltage instability," *IEE Proceedings - Generation, Transmission and Distribution*, vol. 145, no. 2, p. 175, 1998.

[41] T. Amraee, A. Ranjbar, B. Mozafari, and N. Sadati, "An enhanced under-voltage load-shedding scheme to provide voltage stability," *Electric Power Systems Research*, vol. 77, no. 8, pp. 1038–1046, 2007.

[42] C. Moors, D. Lefebvre, and T. V. Cutsem, "Design of load shedding schemes against voltage instability," *2000 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.00CH37077)*.

[43] H. G. Sarmiento, R. Castellanos, G. Pampin, G. Villa, and M. Mirabal, "Revisiting Undervoltage Load Shedding Schemes: A step by step approach," *2008 IEEE/PES Transmission and Distribution Conference and Exposition*, 2008.

[44] T. Amraee, A. Ranjbar, B. Mozafari, and N. Sadati, "An enhanced under-voltage load-shedding scheme to provide voltage stability," *Electric Power Systems Research*, vol. 77, no. 8, pp. 1038–1046, 2007.

[45] V. Nikolaidis and C. Vournas, "Design Strategies for Load-Shedding Schemes Against Voltage Collapse in the Hellenic System," *IEEE Transactions on Power Systems*, vol. 23, no. 2, pp. 582–591, 2008.

[46] D. Lefebvre, S. Bernard, and T. V. Cutsem, "Undervoltage load shedding scheme for the Hydro-Quebec system," *IEEE Power Engineering Society General Meeting, 2004.*

[47] V. Ajjarapu, *Computational techniques for voltage stability assessment and control*. New York: Springer, 2011.

[48] P. Kundur, *Power system stability and control*. Estados Unidos de America: McGraw Hill, 1994.

[49] T. V. Cutsem and C. Vournas, *Voltage stability of electric power systems*. New York: Springer, 2008.

[50] F. Karbalaei, H. Soleymani, and S. Afsharnia, "A comparison of voltage collapse proximity indicators," *2010 Conference Proceedings IPEC*, 2010.

[51] C. Reis and F. M. Barbosa, “Line indices for voltage stability assessment,” *2009 IEEE Bucharest PowerTech*, 2009.

[52] C. Reis and F. Barbosa, “A Comparison of Voltage Stability Indices,” *MELECON 2006 - 2006 IEEE Mediterranean Electrotechnical Conference*.

[53] N. A. M. Ismail, A. A. M. Zin, A. Khairuddin, and S. Khokhar, “A comparison of voltage stability indices,” *2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014)*, 2014.

[54] P. Pourghasem and H. Seyedi, “An under-voltage load shedding scheme to prevent voltage collapse in a microgrid,” *2019 International Conference on Protection and Automation of Power System (IPAPS)*, 2019.

[55] Z. J. Lim, M. Mustafa, and Z. B. Muda, “Evaluation of the effectiveness of voltage stability indices on different loadings,” *2012 IEEE International Power Engineering and Optimization Conference*, 2012.

[56] J. R. Rabunal and J. Dorrado, *Artificial neural networks in real-life applications*. Hershey PA: Idea Group Pub., 2006.

[57] L. C. Jain and A. M. Fanelli, *Recent advances in artificial neural networks: design and application*. Boca Raton: CRC Press, 2000.

[58] K. Mehrotra, C. K. Mohan, and S. Ranka, *Elements of artificial neural networks*. Boulder, CO: NetLibrary, Inc., 1999.

[59] A. E. P. Villa, P. Masulli, and P. R. A. Javi, *Artificial neural networks and machine learning - ICANN 2016: 25th International Conference on Artificial Neural Networks, Barcelona, Spain, September 6-9, 2016, proceedings*. Switzerland: Springer, 2016.

[60] M. Sedighizadeh and A. Eisapour-Moarref, “The Imperialist Competitive Algorithm for Optimal Multi-Objective Location and Sizing of DSTATCOM in Distribution Systems Considering Loads Uncertainty,” *INAE Letters*, vol. 2, no. 3, pp. 83–95, Jan. 2017.

[61] “Evolving Artificial Neural Networks,” *Intelligence Emerging*, 2015.

[62] I. Musirin and T. A. Rahman, "Novel fast voltage stability index (FVSI) for voltage stability analysis in power transmission system," in *Research and Development, 2002. SCOReD 2002. Student Conference on*, 2002, pp. 265-268.

[63] M. Moghavvemi and F. Omar, "Technique for contingency monitoring and voltage collapse prediction," *IEE Proceedings-Generation, Transmission and Distribution*, vol. 145, pp. 634-640, 1998.

[64] M. Chakravorty and D. Das, "Voltage stability analysis of radial distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 23, pp. 129-135, 2001.

[65] M. Moghavvemi and O. Faruque, "Real-time contingency evaluation and ranking technique," *IEE Proceedings-Generation, Transmission and Distribution*, vol. 145, pp. 517-524, 1998.

[66] N. A. Yusof, H. Mohd Rosli, H. Mokhlis, M. Karimi, J. Selvaraj, and N. M. Sapari, "A new under‐voltage load shedding scheme for islanded distribution system based on voltage stability indices," *IEEJ Transactions on Electrical and Electronic Engineering*, vol. 12, pp. 665- 675, 2017.

[67] A. R. Bradley, "Introduction to Matlab," in Programming for Engineers, ed: Springer, 2011, pp. 181-198.

[68] W. J. Palm, "Introduction to Matlab 7 for Engineers," 2005.

[69] Y. Fu, "Hybrid Network Reduction and Artificial Neural Network Based Approaches in Fast Voltage Stability Analysis," The Hong Kong Polytechnic University, 2000

[70] A. Arief, M. Nappu, X. Yin, X. Zhou, and Z. Dong, "Under voltage load shedding design with modal analysis approach," *8th International Conference on Advances in Power System Control, Operation and Management (APSCOM 2009)*, 2009.

[71] A. M. Haidar, A. Mohamed, and A. Hussain, "Vulnerability control of large scale interconnected power system using neuro-fuzzy load shedding approach," *Expert Systems with Applications*, vol. 37, no. 4, pp. 3171–3176, 2010.(25)

[72] A. M. Haidar, A. Mohamed, A. Hussain, and N. Jaalam, "Artificial Intelligence application to Malaysian electrical powersystem," *Expert Systems with Applications*, vol. 37, no. 7, pp. 5023–5031, 2010.(26)

[73] J. Lopes, W. C. Wa, and L. Proenca, "Genetic algorithms in the definition of optimal load shedding strategies," *PowerTech Budapest 99. Abstract Records.*

[74] M. Hosseini-Bioki, M. Rashidinejad, and A. Abdollahi, "An implementation of particle swarm optimization to evaluate optimal under-voltage load shedding in competitive electricity markets," *Journal of Power Sources*, vol. 242, pp. 122–131, 2013.

[75] M. Guichon, M. Melo, A. C. Nieto, M. Vignolo, and N. Yedrzejewski, "Automatic Load Shedding Calculated with genetic algorithms - DAC-CMAG," *2012 Sixth IEEE/PES Transmission and Distribution: Latin America Conference and Exposition (T&D-LA)*, 2012.

[76] H. Çimen and M. Aydın, "Optimal Load Shedding Strategy for Selçuk University Power System with Distributed Generation," *Procedia - Social and Behavioral Sciences*, vol. 195, pp. 2376–2381, 2015.

[77] A. Santos, R. Monaro, D. Coury, and M. Oleskovicz, "Real-Time Closed Loop system controlled by an Artificial Neural Network for Estimation of the Optimal Load Shedding," *12th IET International Conference on Developments in Power System Protection (DPSP 2014)*, 2014.