Coordinat Planning in Improving Power Quality Considering the Use of Non-linear Load in Radial Distribution System

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| **Article Info** |  | **ABSTRACT** (10 PT) |
| ***Article history:***  Received  Revised  Accepted |  | Increasing the burden continuously is also followed by an increase in problem that are quite complex. Power quality has an important role in the distribution of electrical energy. The use of non-linear load can generate harmonic spread which can reduce the power quality in radial distribution system. This research is in form of coordinated planning by combining distributed generation placement, capacitor placement and network reconfiguration simultaneously to minimize active power losses, THD, and voltage deviation as an objective function using particle swarm optimization method. This optimization technique will be tested on two type networks in the form 33-bus and 69-bus IEEE Standart Test System to show effectiveness of the proposed method. The use of MATLAB programming shows the result of simulation of increasing power quality is achieved for all scenario of proposed method. |
| ***Keywords:***  Distributed Generation  Capacitor  Reconfiguration  Coordinat Planning  Particle Swarm Optimization |
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1. **INTRODUCTION**

The economical and technology improvement followed by increasing use of electricity are a major challenge and carry complex problem. The smarter distribution system is expected to drive the good quality of power to distribution system. Nowdays, non-linear load on control devices and power switching apparatus increasing and rapidly due to high efficiency as well as easy of operation and control [1]. The harmonic problems are mainly due to the substantial increase of non-linear load due to technological advances, such as the use of power electronic circuit and devices, in AC/DC transmission links, or in the control of power system using power electronic or microprosessor controller. Increase in harmonic distortion spread will result in additional heating losses, shorter insulation life time, higher temperature and insulation stress, reduced power factor, error on measurement, etc [2-3].

The harmonic source produces a non-sinusidal current which is flawes where each periodic wave is not a sinus form containing harmonic. Reviewing the consequences arising from the distribution of harmonics, Harmonic Load Flow Method is used to determine and analyze the spread and magnitude of harmonic in distribution system [4]. Backward-Forward Method for power flow analysis is used to obtain voltage profile on each bus and active power losses at fundamental frequencies and Harmonic Load Flow is used to obtain the distortion voltage profile on each bus and its harmonic losses caused by use of non-linear loads [5,6].

The use and development of small-scale electric power plants integrated into radial distribution systems is a new breakthrough known as distributed generation (DG). DG is able to improve power quality, environmentally friendly and primary energy sources are easy to obtain and the operation process is very simple [7]. The capacitors are reactive power compensator. However, the same ones can magnify the effect of harmonics of the load due to the existence of resonance with the inductive elements. the effects of capacitor integration on voltage largely depend on their size and placement. however, this can increase or reduce the spread of harmonics in the distribution system [8,9]. Distribution network reconfiguration is a technique that has long been identified as a very useful method for improving performance system by minimizing active power losses, load balancing, improving service and increasing voltage profile each bus in radial distribution system [10].

The distribution of harmonics in distribution systems requires special attention to the planning and design of distribution system expansion. Inadequate planning and operation can worsen the condition of the system and result in damage to equipment due to the spread of harmonics. intelligent planning is able to maintain and improve performance that is summarized in a coordinated planning. coordinated planning is a planning activity that coordinates several optimization techniques to achieve the stated objective function. Several previous studies on the combination of optimization techniques in reducing the spread of harmonics in the distribution system. A combination of network reconfiguration and DG placement using the Branch Exchange Technique Method [10]. Evaluate network reconfiguration and capacitor placement for several types of loads using the non-iterative harmonic load flow method [11]. Capacitor placement and network reconfiguration simultaneously using the New-PSO, ACO, and HS methods [12]. Optimization of placement of distributed energy resources (DG and Capacitor) using the BBO, PSO, ABC, and DE Method [13] and Teaching Learning Based Optimization Method [14].

The combination of three optimization techniques are DG placement, Capacitor placement and reconfiguration using the Genetic Algorithm Method which is summarized in a coordinated plan to maximize optimal power flow [15-16]. This research will discuss the development of previous research related to the optimization of a combination of three optimization techniques that aim to improve power quality to the distribution of harmonics by considering the use of non-linear loads in a radial distribution system using the Particle Swarm Optimization Method.

1. **METHODOLOGY**

**2.1. Objective Function**

Objectvie functions used to optimize optimization technique performed in coordinated planning in this study is in the form of a multi objective function, i.e.

* Minimum active power losses

(1)

(2)

* Minimum total harmonic distortion

(3)

(4)

* Minimum voltage deviation

(5)

(6)

So, the equation of the multi objective function is

(7)

**2.2. Constrain**

* Bus Voltage Limit

(8)

* Total Harmonic Distortion Limit

(9)

* Number and Sizing of DG

The number of DGs to be placed is 4 and the size are.

for IEEE 33-bus tes system (10)

for IEEE 69-bus tes system (11)

* Number and Sizing of Capacitor

The number of Capacitors to be placed is 4 and the size are.

for IEEE 33-bus tes system (12)

for IEEE 69-bus tes system (13)

* The new distribution network topology remains radial condition after activating tie switch and opening sectional switch.

**2.3. Particle Swarm Optimization (PSO)**

In PSO, each particle that is roaming through the *D*-dimensional problem hyperspace represent the potential solution for a specific problem. For each *I* two vectors namely for position vector and for velocity vector. In addition, each particle can memorise its personal best experience ever encountered, represent by personal best position vector . The position attained by the best particle in the society is represented as . Mathematically, at iteration of the searching process, the th dimention of particle ’s velocity, and position are updated as follows [17].

(14)

(15)

Parameter PSO used are population = 100, iteration = 100, = 0.5, = 0.5, = 0.5, = 2 and = 2. The stages of the research carriedout can be seen in figure 1.



Figure 1. Flowchart of research stages.

**2.4. Object Data and Study Case**

**2.4.1. Harmonic Source**

The harmonic sources will be given to load bus which aims to generate the distribution of harmonics ini radial distribution system which can be seen in Table 1.

Table 1. Injection of harmonic source in load bus [18].

|  |  |  |
| --- | --- | --- |
| Orde | Magenetude (%) | Angle |
| 5 | 98 | 140 |
| 7 | 39.86 | 113 |
| 11 | 18.85 | -158 |
| 13 | 9.79 | -178 |
| 17 | 2.5 | -94 |

**2.4.2. IEEE 33-bus**

On IEEE-33 bus, there are 32 sectionals switchs and 5 tie switches can be seen in Figure 2. Harmonic source will be injected on bus 5, 7, 9, 11, 14, 17, 20, 24, 27, 29, 31 and 33.



Figure 2. IEEE-33 bus tes system.

**2.4.3. IEEE 69-bus**

On IEEE-69 bus, there are 47 sectional switchs and 5 tie switches can be seen in Figure 3. Harmonic source will be injected on bus 6, 9, 14, 17, 22, 27, 33, 37, 40, 43, 49, 55, 61, and 69.



Figure 3. IEEE-69 bus tes system

**2.4.4. Study Case**

This research conducted a simulation of several study cases to determine the effect of optimization techniques on coordinated planning in finding the objective function, namely;

1. Scenario 1 (S-1). Normal case
2. Scenario 2 (S-2). Network Reconfiguration
3. Scenario 3 (S-3). DG Placement
4. Scenario 4 (S-4). Capacitor Placement
5. Scenario 5 (S-5). DG Placement and Capacitor Placement
6. Scenario 6 (S-6). DG Placement and Network Reconfiguration
7. Scenario 7 (S-7). Capacitor Placement and Network Reconfiguration
8. Scenario 8 (S-8). DG Placement, Capacitor Placement and Network Reconfiguration
9. **RESULTS AND DISCUSSIONS**

Harmonic current injection at load by placing harmonic source will generate harmonics spread on the system. The search results of the optimization techniques carried out in coordinated planning based on a predetermined scenario using the Particle Swarm Optimization Method.

**3.1. IEEE 33-bus Tes System**

The result of the optimization technique perfomed can be seen in Table 2, Figure 4, Figure 5 and Figure 6.

Table 2. Result of study case IEEE 33-bus tes system.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameter | | S.1 | S.2 | S.3 | S.4 | S.5 | S.6 | S.7 | S.8 |
| Fitness | | - | 38.722 | 41.508 | 66.208 | 38,193 | 37.670 | 40.219 | 25.456 |
| DG (kW) | Loc | - | - | 7, 9, 17, 31 | - | 13, 17, 29, 31 | 9, 12, 10, 20 | - | 7, 16, 29, 31, |
| Sizing | - | - | 200, 200, 200,200 | - | 200, 200, 200, 200 | 200, 200, 70.21, 200 | - | 200, 200, 200, 200 |
| Cap (kVar) | Loc | - | - | - | 8, 15, 17, 26 | 3, 17, 25, 29 | - | 6, 7, 14, 32 | 5, 8, 31, 33 |
| Sizing | - | - | - | 50, 50, 50, 50 | 50, 50, 50, 50 | - | 50, 50, 50, 50 | 50, 50, 50, 50 |
| Active Tie | | - | 8-21 | - | - | - | 12-22 | 12-22 | 8-21 |
| Sec Tie Open | | - | 6-7 | - | - | - | 10-11 | 8-9 | 7-8 |
| (kW) | | 122.03 | 64.16 | 68.75 | 114.81 | 63.08 | 65.43 | 71.60 | 39.18 |
| (kVAr) | | 87.86 | 55.19 | 38.63 | 82.7 | 35.54 | 46.99 | 50.77 | 27.39 |
| THD max | | 5.116 | 3.368 | 2.568 | 4..793 | 2.161 | 3.363 | 3.632 | 2.636 |
| THD min | | 0.456 | 0.300 | 0.272 | 0.451 | 0.295 | 0.011 | 0.007 | 0.197 |

In IEEE 33-bus tes system, the total peak demand of system is 4.37 MVA, power factor is 0.85. All data on this system is in per-unit (pu) form where the best values of power and voltage is 100 MVA and 12,66 kV. Table 2 shows the simulation results for all scenarios for the IEEE 33-bus test system. The use of PSO Algorithm is able to provide the best solution for the planning carried out. Simulation results for all scenarios vary based on the ability of the optimization techniques used in finding desired solutions that are seen by decreasing the value of fitness. Scenario 8 provides the best solution in this plan that can reduce total active power losses by 67.89% or 82.85 kW both in terms of fundamental or each order of harmonic distortion.

Reviewing the spread of harmonic distortion also improved with a decrease in THDv value (%) on each bus that did not pass IEEE Standard 519-1992 as shown in Figure 4. Each scenario has its own performance in reducing the spread of harmonic distortion to the use or combination of optimization techniques used. Figure 5 shows that all the techniques used are able to improve the voltage profile better than the baseline condition (Scenario 1) without exceeding the allowable limit so that the voltage deviation value in each load bus decreases as shown in Figure 6.

Figure 4. THDv value on each bus for all scenarios for IEEE 33-bus tes system.

Figure 5. Level of voltage bus on each bus for all scenario for IEEE 33-bus tes system.

Figure 6. Voltage Deviation value on each bus for all scenario for IEEE 33-bus tes system.

The use of optimization techniques that are single from the three optimization techniques that provide the best solution is reconfiguration network (S-2). Network reconfiguration is able to change the value of network impedance that can change the electric current flowing and repair voltage levels followed by reduced active power losses. The magnitude of the spread of Harmonic distortion in the system is very dependent on the current flowing at the load and the voltage level on each bus so that the spread of harmonic distortion can be reduced by network reconfiguration techniques as in research [10, 19,20]. The size of DG placement and Capacitor placement resulting in the use of the PSO algorithm are at the maximum limit in other words the performance of the system will be better in improving the quality of power with a size of DG > 200 kWatt and Capacitors > 50 kVAr. The combination of three optimization techniques simultaneously can provide the best performance to improve power quality in reducing the spread of harmonic distortion.

**3.2. IEEE 69-bus Tes System**

The result of the optimization technique perfomed can be seen in Table 3, Figure 7, Figure 8, and Figure 9.

Table 3. Result of study case IEEE 69-bus tes system.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameter | | S.1 | S.2 | S.3 | S.4 | S.5 | S.6 | S.7 | S.8 |
| Fitness | | - | 77.5693 | 99.6067 | 113.6014 | 93,2101 | 79.3485 | 83.6948 | 76.1402 |
| DG (kW) | Loc | - | - | 23, 51, 61, 63 | - | 27, 36, 59, 65 | 2, 20, 24, 45 | - | 10, 11, 37, 56 |
| Sizing | - | - | 231, 193, 241, 214 | - | 192, 95, 219, 232 | 163, 157, 190, 122 | - | 29, 120, 170, 87 |
| Cap (kVar) | Loc | - | - | - | 14, 17, 21, 27 | 9, 32, 36, 65 | - | 5, 43, 50, 66 | 29, 47, 60, 69 |
| Sizing | - | - | - | 65, 62, 93, 77 | 47, 26, 87, 81 | - | 60, 25, 76, 38 | 6, 71, 6, 91 |
| Active Tie | | - | 50-59 | - | - | - | 11-43 | 11-43 | 50-59 |
| Sec Tie Open | | - | 58-59 | - | - | - | 8-9 | 8-9 | 55-56 |
| (kW) | | 270.05 | 168.66 | 208.30 | 255.16 | 214.59 | 192.32 | 202.46 | 163.04 |
| (kVAr) | | 248.32 | 258.26 | 199.41 | 235.79 | 212.59 | 177.75 | 180.85 | 251.21 |
| THD max | | 7.673 | 7.663 | 6.827 | 7.561 | 7.384 | 6.414 | 6.372 | 7.539 |
| THD min | | 0.006 | 0.006 | 0.005 | 0.006 | 0.005 | 0.001 | 0.001 | 0.005 |

In IEEE 69-bus tes system, the total peak demand of system is 4.66 MVA, power factor is 0.81. All data on this system is in per-unit (pu) form where the best values of power and voltage is 100 MVA and 12,66 kV. Table 2 shows the simulation results for all scenarios for the IEEE 69-bus test system.

Berbeda dengan IEEE 33-bus tes system, dengan total beban yang hamper sama, IEEE 69-bus tes system memiliki jumlah bus beban yang lebih banyak sehingga impedansi jaringan semakin besar sehingga penyebaran harmonic distortion berupa THDv melebih batas yang diizinkan hingga 7,673 % pada bus 65 selain itu nilai reactive power losses pada orde ke-5 sebesar 128.41 kVar yang lebih besar dari nilai fundamentalnya.. Penggunaan metode PSO dari seluruh scenario yang ada dapat menginkatkan power quality dimana adanya penurunan active power losses sebesar 39.62% atau 107,01 kWatt pada scenario 8 dan 37,54% atau 101,39 kWatt pada scenario ke 2.

Figure 7. THDv value on each bus for all scenarios for IEEE 69-bus tes system.

Figure 8. Level of voltage bus on each bus for all scenario for IEEE 69-bus tes system.

Figure 9. Voltage Deviation value on each bus for all scenario for IEEE 69-bus tes system.

The reduction in the spread of harmonic distortion occurs in every scenario that is seen that is seen in Figure 7 but still exceeds the allowed limit. The improvement of the voltage level on each bus and the reduced voltage deviation that can be seen in Figure 8 and Figure 9. The use of optimization techniques, both single and plural, has been said to improve the performance of the system in terms of improving the quality of power against the spread of harmonic distortion but not yet maximized.

1. **CONCLUSION**

In this paper, the use of the PSO Algorthm is able to provide a search for solution to all scenarios carried out in finding the objective function in increasing power quality to the spread of harmonics. The simulation results verify that the effectiveness of the proposed method and also the solution to all scenarios carried out. Planning that gives maximum result is in scenario 9 in the form of a combination of three simultaneous optimization techniques between DG placement, Capactior placement and network reconfiguration of the two objects used. Taking into account harmonic distortion resulting from the use of non-linear loads in the radial distribution system as a multi-objective function provides the appropriate criteria in carrying out this planning. Futher planning is needed regarding the handling of harmonics distribution in a larger distribution system which will be discussed in the next paper with other method.

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**REFERENCES**

1. P. Bagheri, W. Xu, T. Ding*.*, "A Distributed Filtering Scheme to Mitigate Harmonic in Residential Distribution System," *IEEE Transactions Power Delivery,* Vol 31. No 2, pp. 648-656, 2016.
2. M. Mohammadi., “Bacterial Foraging Optimization and Adaptive Version for Economically Optimum Sitting, Sizing and Harmonic Tuning Orders Setting of LC Harmonic Passive Filters in Radial Distribution System with Linear and Nonlinear Loads,” *Elsevier Applied Soft Computing*, Vol. 29, pp. 345-356, 2015.
3. M.D. Faraby, O. Penangsang., “A Study of Harmonic Spreading Against Distribution Network Reconfiguration in Passive Radial Distribution Systems,” *4th International Conference Science and Technology, Yogyakarta, Indonesia*, 2018.
4. A. Denyal, O. Penangsang, D.A. Asfani., “Pemodelan Sistem Distribusi Radial Untuk Studi Aliran Daya Harmonisa Tiga Fasa,*” Jurnal Teknik POMITS*, Vol. 1No. 1, 2013, pp. 1-6, 2013.
5. J.H. Teng & C.Y., Chang, “Backward/Forward-Based Harmonic Analysis Method for Distribution System,” *IEEE Transaction on Power Delivery*, Vol. 22, No. 3, pp. 1665-1671, 2007.
6. M.D. Faraby, O. Penangsang., “Impact Optimal DG Placement Against Harmonic Distribution on Reconfiguration Distribution Network on Microgrid System,” *IOP Conference Series: Material Science and Engineering*, Vol. 676, 2018.
7. R. Shayani, M.D. Oliveira., “Photovoltaic Generation Penetration Limit in Radial Distribution System,” *IEEE Transaction Power System*, Vol. 26, No. 3, pp. 619-624, 2011.
8. M.S.S. Azevedo, I.P. Abril, J.C. Leite., “Capacitor Placement by NSGA-II in Distribution System with Non-Linear Loads,”*Elsevier Electrical Power and Energy System*, Vol. 82, pp. 281-287, 2016.
9. V. Jovica, M. Todoroyski., “Optimal Capacitor Placement in Distorted Distribution Netwok With Different Load Model Using Penalty Free Genetic Algorthm”, *Elsevier Electric Power and Energy System*, pp. 174-182, 2016.
10. Yaidah Ch, S.K. Goswami, D. Chatterjee., “Effect of Network Reconfiguration on Power Quality of Distribution System,” *Elsevier Electrical Power and Energy System*, Vol. 83, pp. 87-95, 2016.
11. M.A. Amini, A. Jalilia, M.R.P. Behbahani., “Fast Network Reconfiguration in Harmonic Polluted Distribution Network Based on Developed Backward/Forward Sweep Harmonic Load Flow,” *Elsevier Electric Power System Research*, Vol 168, pp. 295-304, 2019.
12. F. Sayadi, S. Esmaeili, F. Keynia., “Feeder Reconfiguration and Capacitor allocation in the Presence of Non-Linear Loads Using New-PSO Algorithm,” *IEEE IET Generation, Transmission & DistributionI,* Vol. 10, pp. 2316-2326, 2016.
13. S. Biswas, S.K. Goswami, A. Chatterjee., “Optimal Distributed Generation Placement in Shunt Capacitor Compensated Distribution System Considering Voltage Sag and Harmonic Distortion,” *IEEE IET Generation, Transmission and Distribution*, Vol. 8, pp. 783-797, 2014.
14. M. Kumawat, N. Gupta, N. Jain, R.C. Bansal., Optimal Planning of Distributed Energy Resources in Harmnonic Polluted Distribution System,” *Elsevier Swarm and Evolutionary Computation*, Vol. 39, pp. 99-113, 2018.
15. E.P. Santoso, O. Penangsang, N.K. Aryani, “Optimasi Penentuan Lokasi Kapasitor dan Distributed Generation (DG) Dengan Rekonfigurasi Jaring Untuk Meningkatkan Keluaran Daya Aktif DG Pada Sistem Distribusi Radial Menggunakan Genetic Algorithm (GA),” *Jurnal Teknik ITS,* Vol. 5, No. 2, ISSN: 2337-3539, 2016.
16. Suyanto, “Decision Support System (DSS)- CP Berbasis Advanced OPF HCT : Simulator Perencanaan, Operasi dan Optimasi Jaringan Sistem Distribusi Radial,” Disertation, Insitute Technology of Sepuluh Nopember, Surabaya, Indonesia, 2018.
17. J. Kennedy, R. Eberhard., “Particle Swarm Optimization,” *International Conference Neural Network, Piscataway, NJ*, pp. 1942-1948, 1995.
18. A. Rosyadi, O. Penangsang, A. Soeprijanto., “Optimal Filter Placement and Sizing in Radial Distribution System Using Whale Optimization Algorithm,” *International Seminar on Intelligent Technology and Its Application, Surabaya, Indonesia*, 2017.
19. S. Jazebi, B. Vahidi., “Reconfiguration of Distribution Network to Mitigate Utilities Power Quality Disturbances,” *Elsevier Electric Power System Research*, Vol 91, pp. 9-17, 2012.
20. S. Jazebi, M.M. Hadji, R.A. Naghizadeh., “Distribution Network Reconfiguration in the Presence of Harmonic Load : Optimization Techniques and Analysis,” *IEEE Transaction on Smart Grid*, Vol. 5, No. 4, pp. 1929-1937, 2014.

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