Single Tuned Filter Planning to Mitigate Harmonic Polluted in Radial Distribution Network Using Particle Swarm Optimization

1st Muhira Dzar Faraby
Department of Mechatronic Engineering
Polytechnic of Bosowa
Makassar, Indonesia
muhira_faraby@yahoo.com

2nd Andi Fitriati
Department of Mechatronic Engineering
Polytechnic of Bosowa
Makassar, Indonesia
andi.fitriati@bosowa.ac.id

3rd Christiono
Department of Electricity & Renewable Energy
Institute Technology of PLN
Jakarta, Indonesia
christiono@itpln.ac.id

4th Usman
Department of Electrical Engineering
Polytechnic State of Ujung Pandang
Makassar, Indonesia
usman.ose@poliupg.ac.id

5th Akhyar Muchtar
Department of Education of Electrical Engineering
University State of Makassar
Makassar, Indonesia
akhyarmuchtar@unm.ac.id

6th Andi Nur Putri
Department of Electrical Engineering
Institute Technology of Sepuluh Nopember
Surabaya, Indonesia
andiputri.19071@mhs.ee.its.ac.id

***Abstract*—The increasing of nonlinear load has a currently become recurring problem which can worsen the condition of the system. Effect of placement and sizing single tuned filter on power quality of radial distribution system has been investigated to minimum power losses on passive and active system (after DG Placement). Particle Swarm Optimization (PSO) has been used to establish of the objective function. The effectiveness of method on power quality issues have been studied on IEEE 33-bus Standard System using MATLAB. The simulation result verified that using nonlinear load on each case the proposed strategy can be a robust approach to improve performance system on power quality for mitigate harmonic polluted.**

Keywords*—*Single Tuned Filter, Harmonic, DG, PSO, Power Quality.

I. INTRODUCTION

Increasing energy demand is a major to challenge in the future electrical power energy. Nowadays non-linear load and power switching apparatus are increasing rapidly due to high efficiency as well as ease and operation and control but can generate harmonic spread in distribution system [1]. Harmonic is the one indicator of the quality of the electric power. IEEE Standard 519-2014 mentions a harmonic as a sinusoidal voltage or current having a multiple of the of the spheres and the frequency at which the power system is design to be operated [2].

The harmonic source produces a non-sinusoidal current which is flawed where each periodic wave is not a sinus form containing harmonic. Nonlinear load is the cause of high current harmonics on the system and can improve power losses in distribution system which can damage the equipment [3]. Various techniques have been developed to overcome the harmonic effect that arise in both active and passive filter placement. In this research selected passive filter namely single tuned filter type. Single tuned filter is expected to provide a more effective and economical solution in maintaining the power quality of power distribution system [4].

To find out the effect of harmonic spreading on radial distribution system (RDS), a harmonic power flow analysis is perform. The harmonic spread on RDS can be analyzed using Forward-Backward Sweep Power Flow Method as well as harmonic power flow (HLF) [5]. The most of voltage and current distortion in radial distribution system is arose to harmonics of third, fifth, and seven orders because using linear and nonlinear loads in distribution system, passive filter planning is much difficult. [6],

Active power losses reduction and voltage profile improvement, together with THD reduction planning of distribution electrical system with presence of DG requires the definition of several factors such as, the best technology to be used, the number and the capacity of the units, the best location, type of network connection and etc [6]. Especially in handling the harmonic spread, the output power released by DG has been maximized after placement 4 unit of DG in different location [7,8]

Intelligent distribution system is expected to drive good power quality to the system with optimal planning. Not optimal planning causes are the objective function to be achieved are not met even can worsen the condition of the system [9]. The use of the artificial intelligence method in optimizing location and sizing of the single tuned filter, namely whale algorithm [3] NSGA-II [9], ant colony [10], etc. Due to that, in this research the implantation single tuned filter placement used to dampen the 5th harmonic spread in radial distribution system to minimize power losses which will be tested on IEEE 33-bus standard passive and active (after placement DG [8]) radial distribution system using Particle Swarm Optimization.

II. MODELING SYSTEM

A. Harmonic Power Flow

The Harmonic Load Flow Algorithm (HPF) was introduced by Teng [5]. The Backward sweep algorithm of harmonic load flow is uses to obtain matrix $[A]$ representing the relationship between the branch current and injection current bus for h harmonic sequence. The forward sweep produced a $[HA]$ matrix representing the relationship between harmonic bus voltage and harmonic bus injection current. To find current flowing from $i-j$ branch used Backward sweep current equation;

$$\left[B_{i-j}^{(h)}\right] = \left[A_{i-j}^{(h)}\right] * \left[I_{i-j}^{(h)}\right] \quad (1)$$

$$[A_{i-j}^{(h)}] = \begin{bmatrix} Ah_{i-j}^{(h)} \\ \cdot \\ \cdot \\ Ah_{i-j}^{h} \end{bmatrix} \quad (2)$$

where $[A_{i-j}^{(h)}]$ is coefficient vector of branch $i-j$ to the presence of harmonic current absorbed. To get harmonic voltage each bus used Forward Sweep voltage equation;

$$[V_{i-j}^{(h)}] = [Z_{i-j}^{(h)}] * [B_{i-j}^{(h)}] \quad (3)$$

$$[V_j^{(h)}] = [V_j^{(h)}] - [V_{i-j}^{(h)}] \quad (4)$$

$$[V^{(h)}] = [HA^{(h)}] * [I^{(h)}] \quad (5)$$

The value of the harmonic voltage bus is calculated with an iteration less than or an equal to the tolerance determined by Ɛ.

$$\left|V_i^{(h),k+1} - V_i^{(h),k} \leq \text{Ɛ}\right| \quad (6)$$

Total active power losses can be written with vector from as follows;

$$P_{Loss}^{(h)} = \sum_{i=1}^{br} P_{Loss_i}{}^{(h)} = \sum_{i=1}^{bt} \sum_{h=h_0}^{h_{max}} \left|B_i{}^{(h)}\right|^2 R_i{}^{(h)} \quad (7)$$

$$P_{Loss}^{(h)} = \left[R^{(h)}\right]^T * \left[A^{(h)}\right] * \left[I^{(h)}\right]^T \quad (8)$$

The voltage values of rms bus i (V_{rms_i}) and THD can be calculated as follows;

$$V_{rms_i} = \sqrt{\left|V_i^{(1)}\right|^2 + \sum_{h=h_0}^{h_{max}} \left|V_i^{(h)}\right|^2} \quad (9)$$

$$THD = \frac{\sqrt{\sum_{h=h_0}^{h_{max}} \left|V_i^{(h)}\right|^2}}{\left|V_i^{(1)}\right|^2} \quad (10)$$

B. Single Tuned Filter

The harmonic filter is designed to reduce the amplitude of one or more frequencies of a voltage or current. With the installation of a harmonic filter on an electrical power system containing a harmonic source, the spread of harmonic current throughout the network can be minimized. On the other hand harmonic filters at fundamental frequencies can compensate for the reactive power used to improve the system power factor [11].

Single tuned filter is one passive filter consisting of passive components that R, L and C are connected in series. This filter is most widely used in industrial power systems in terms of overcoming harmonics, this is because single tuned filters are more efficient.

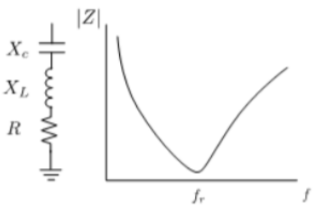

Fig 1. Single tuned filter circuit and the frequency impedance curve [3].

C. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is one of evolutionary computing techniques, in which the population on PSO is based on algorithmic search and begins with a random population called a particle. The standard procedure in applying PSO algorithm starts from population initialization, fitness function evaluation, compare fitness particle evaluation with P_{best}, identifies particle result at best fitness value, update position of particle and determines direction with best fitness on specified iteration [12].

III. Methodology

A. Objective Function

The purpose of this research is to find a multi-objective function in the form of

- Minimal total power losses

$$P_{Loss} = \sum_{i=1}^{nb} P_{Loss_i}{}^{(1)} + \sum_{i=1}^{nb} \sum_{h=h_0}^{h_{max}} P_{Loss_i}{}^{(h)} \quad (11)$$

$$f(x) = \min P_{Loss} \quad (12)$$

B. Constrain

- Bus Voltage Limit

$$V_{min}(0.95\ pu) \leq V_{rms_i} \leq V_{max}(1.05\ pu) \quad (13)$$

- Total Harmonic Distortion Limit

$$THD_i(\%) \leq THD_{max} \quad (14)$$

C. Single Tuned Filter Design

The step in designing single tuned filter on radial distribution system;

- Step 1. Determine X_c and C on fundamental frequency

$$X_c = \frac{V^2}{Q_{filter}} \quad (15)$$

$$C = \frac{1}{2\pi f X_c} \quad (16)$$

- Step 2. Specifies X_L and L at tuning frequency

$$L = \frac{1}{C(2\pi f_{tun})^2} \quad (17)$$

$$X_L = 2\pi f L \quad (18)$$

- Step 3. Calculate the R value for Q quality

$$R = \frac{X_n}{Q} \quad (19)$$

$$X_n = \sqrt{\frac{L}{C}} \quad (20)$$

From the single tuned filter design step above, we will get impedance from filter;

$$Z_{filter} = R + j(X_L - X_c) \quad (21)$$

So, the harmonic frequency the h impedance of the single tuned filter is;

$$Z_{filter}{}^{(h)} = R^{(h)} + j\left(X_L{}^{(h)} - X_c{}^{(h)}\right) \quad (22)$$

D. Optimization by PSO

Optimization in determining filter size and location using PSO. The steps of PSO are;

- Initialization of population of particle by position and velocity is random in a search dimension space
- Evaluate the fitness function of each particle

- Compare evaluation of particle with P_{best}
- Update *velocity* and *particle* position
- Back to step 2if the criteria are met, it usually stops if the fitness value improves.

The PSO Algorithm as follows;

$$V_{id}(t+1) = V_{id}(t) + c_1 rand_1 (P_{id}(t) - X_{id}(t)) + c_2 rand_2 (P_{gd}(t) - X_{id}(t)) \quad (23)$$

$$X_{id}(t+1) = X_{id}(t) + V_{id}(t+1) \quad (24)$$

Parameter of PSO used are, population = 100; iteration = 50; c_1 = 2; c_2 = 2. The step of reasearch carried out can be seen in Figure 2.

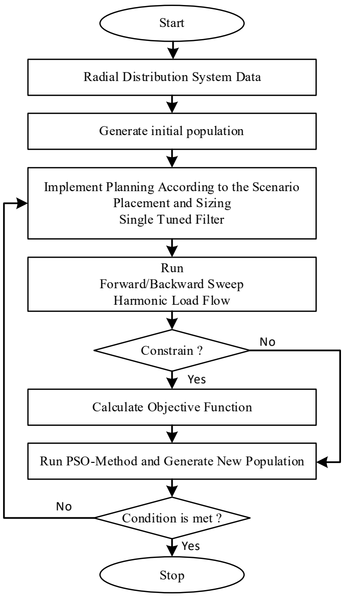

Fig 2. Step of the research.

E. IEEE 33-bus and Study Case

- IEEE 33-bus standard system.

  The Harmonic source will be injected on bus 5, 7, 9, 11, 14, 17, 20, 24, 27, 29, 31 and 33.

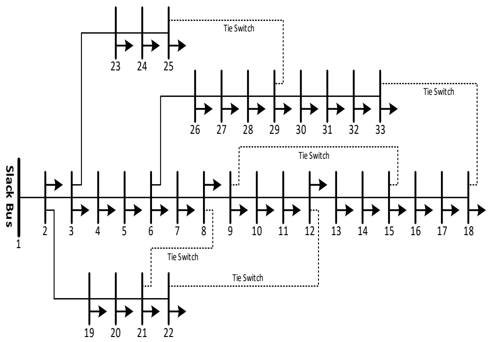

Fig 3. IEEE 33-bus system.

- Harmonic Source

  The harmonic source will be given to load bus which aims to generate harmonic spread in radial distribution system which can be seen in Table 1.

TABLE 1. INJECTION OF HARMONIC SOURCE IN LOAD BUS

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

- Study Case

  This research conducted a simulation of several scenario to determine the effect of optimization placement and sizing to find the objective function, namely;

  1) Scenario 1 (S-1). Normal Case
  2) Scenario 2 (S-2). Optimal Placement and Sizing 4 units DG 200 kW in bus 7, 9 17 and 31 by PSO (active distribution system) [8].
  3) Scenario 3 (S-3). Optimal Placement and Sizing Single Tune Filter in Scenario 1.
  4) Scenario 4 (S-4). Optimal Placement and Sizing Single Tuned Filter in Scenario 2.

IV. RESULT AND DISCUSSIONS

The proposed method explained was programmed in MATLAB R2018b and tested on IEEE 33-bus standard system. The result obtained are explain in the following sections.

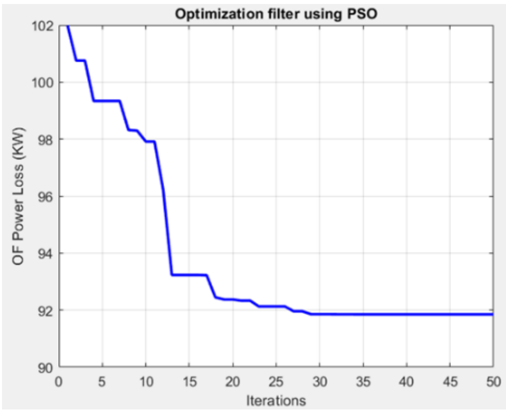

Fig 4. Iteration after optimization with PSO in Scenario 3.

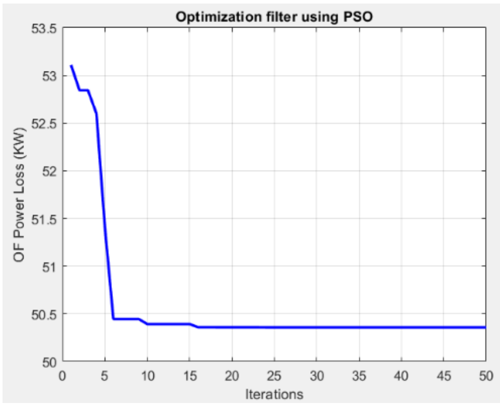

Fig 5. Iteration after optimization with PSO in Scenario 4.

The total active power losses for fundamental and harmonic is calculated. The result of PSO is shown in Figure 4 and Figure 5. The optimum filter size search is 1421,6 kVAr in bus 6. PSO for test system converged in 29 iterations for Scenario 3. The filter size search is 1374,1 kVAr in bus 6. PSO for test system converged in 16 iteration for Scenario 4. The PSO search in Scenario 4 uses a system that has been optimized for DG placement (active distribution system) so thet the PSO search is completed faster than in Scenario 3.

The result of harmonic load flow analysis before and after placement and sizing single tuned filter is presented in Figure 7, Figure 8. Figure 9 and Figure 10. Figure demonstrates the reduction of active power losses for fundamental harmonic frequency 5th orders and total active power losses. Figure 8 and Figure 9 show reduction of voltage THD and harmonic distortion 5th order after optimalization. Figure 9 show improvement voltage level in to each bus before and after placement.

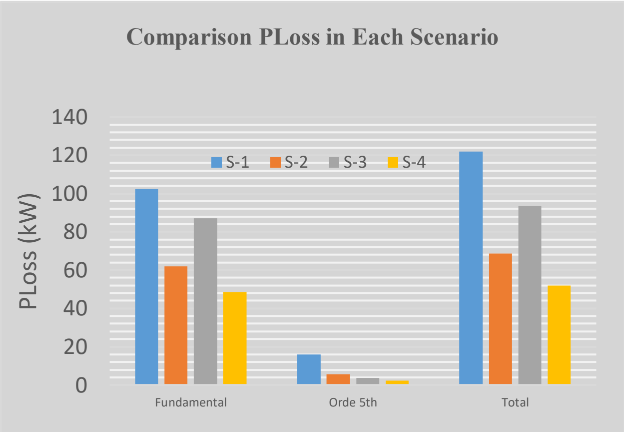

Fig 6. Comparison P_{Losses} in Each Scenario.

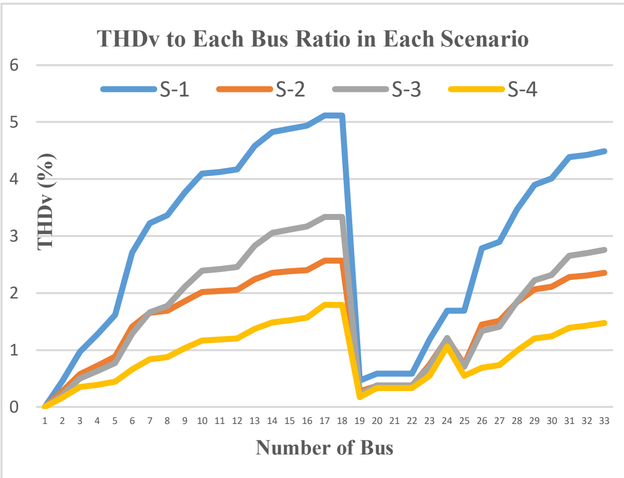

Fig 7. Comparison THDv in Each Scenario

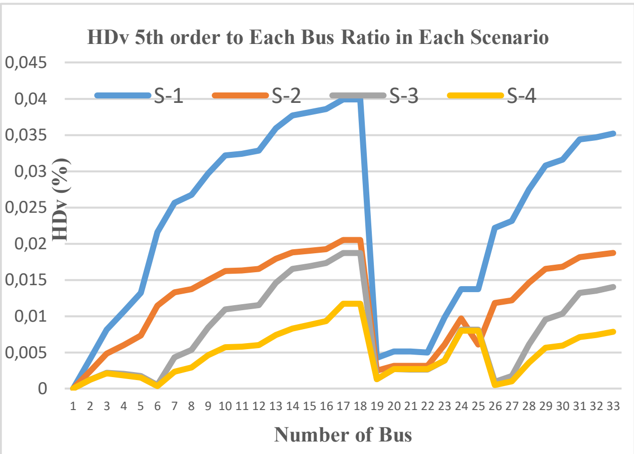

Fig 8. Comparison harmonic distortion 5th order in Each Scenario.

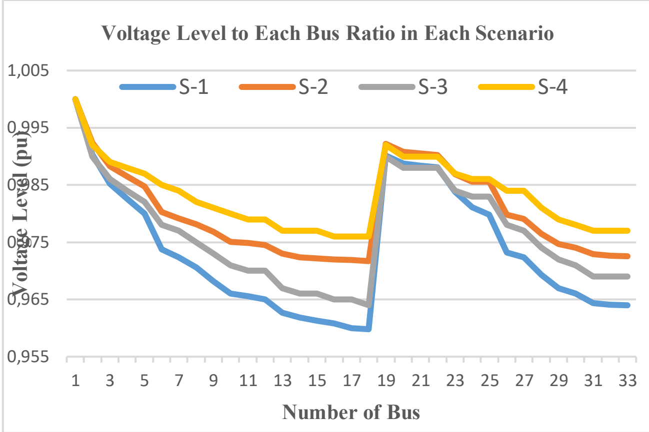

Fig 9. Comparison voltage level bus in each scenario.

From Figure 6 can be seen after optimalization, the total active power losses which was 122,03 kW is lowered to 93,40 kW or 23,46% for Scenario 3 and 68,75 kW is lowered to 51,90 kW or 24,51% for Scenario 4. Scenario 4 has shown a distribution system that has integrated distributed generation will be maximized if a filter is placed with the aim of increasing power quality in mitigating the spread of harmonic distortion.

V. Conclusion

The use of PSO in a placement and sizing single tuned filter that aims to minimize active power losses in radial distribution system, keep the rms voltage with the prescribed limit, and decreasing the total harmonic distortion level. It only takes 29 iterations on scenario 3 and 16 iteration in scenario 4 for PSO to find best possible solution. An IEEE 33-bus radial distribution system is used to validate the result. Best filter size for test system is 1421,6 kVAr in bus 6 for scenario 3 and 1374,1 kVAr in bus 6 for scenario 4. The total active power losses improvement is 23,46 % for scenario 3 and 24,51 % for scenario 4. Systems performance in mitigating the spread of harmonic distortion is very good for placement DG and single tuned filter in radial distribution system. The proposed methodology used can be easily to other radial distribution system. The next research will discuss filter combination with other optimization techniques that can improve power quality in overcoming the spread of harmonic distortion.

Acknowledgment

Thank you very much for Ministry of RISTEK for financial support in Novice Lecture Research “PDP” , Lecture in Department of Mechatronic Engineering, Polytechnic of Bosowa and all of my friend in Alumnus Magister of Electrical Engineering, University of Hasanuddin 2012.

References

[1] M. Kumawat, N. Gupta, N. Jain, R.C. Bansal, “Optimal Planning of Distributed Energy Resource in Harmonic Polluted Distribution System,” Elsevier Swarm and Evolutionary Computation, Vol. 39, pp. 99-113, 2018.

[2] D. Marsudi, “Pembangkit Tenaga Listrik Second Edition,” Erlangga, Jakarta, Indonesia, 2011.

[3] A. Rosyadi, O. Penangsang, A. Soeprijanto, “Optimal Filter Placement and Sizing in Radial Distribution System Using Whale Optimization Algorithm,” 2017 International Seminar on Intelligent Technology and Its Application,” pp. 87-92, 2017.

[4] I.W. Rinas, “Analisis Perbandingan Penggunaan Filter Pasif dan Filter Aktif Untuk Menanggulangi Terhad Pada Sistem Kelistrikan di Ruang

Puskom Jurusan Teknik Elektro Fakultas Teknik Universitas Udayana," Jurnal Teknologi Elektro, Vol. 10, pp. 20-26, 2011.

[5] J. Teng, C. Chang, "Backward Forward Sweep-Based Harmonic Analysis Method for Distribution System," IEEE Transaction on Power Delivery, Vol. 22, No. 3, pp. 1665-1672, 2007.

[6] O. Amanifar, "Optimal distributed generation placement and sizing for loss and THD reduction and voltage profile improvement in distribution systems using Particle Swarm Optimization and sensitivity analysis," *16th Electrical Power Distribution Conference*, Bandar Abbas, 2011, pp. 1-7, 2011.

[7] 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.

[8] M.D. Faraby, O. Penangsang, R.S. Wibowo, A. Fitriati, "Coordinate Planning in Improving Power Quality Considering the Use of Nonlinear Load in Radial Distribution Netwok," unpublished.

[9] A. S. Abbas, E. S. Ali, R. A. El-Sehiemy, A. A. A. El-Ela and K. M. Fetyan, "Comprehensive Parametric Analysis of Single Tuned Filter in Distribution Systems," *2019 21st International Middle East Power Systems Conference (MEPCON)*, Cairo, Egypt, pp. 465-472, 2019.

[10] F. M. Alhaddad and M. El-Hawary, "Optimal Filter Placement and Sizing Using Ant Colony Optimization in Electrical Distribution System," *2014 IEEE Electrical Power and Energy Conference*, Calgary, AB, pp. 128-133, 2014.

[11] W. Prasetyadi, R. S. Wibowo, dan O. Penangsang, "Evaluasi Harmonisa dan Perancanaan Filter Pasif Pada Sisi Tegangan 20 kV Akibat Penambahan Beban Pada Sistem Kelistrikan Pabrik Semen Tuban", Jurnal Teknik POMITS, Vol. 1, pp 1-6, 2012

[12] J. Kennedy, R. Eberhard., "Particle Swarm Optimization," *International Conference Neural Network, Piscataway, NJ*, pp. 1942-1948, 1995.