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The Effect of Single Tuned Filter on Coordinated Planning in Increasing Power Quality in Radial Distribution System

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***Abstract*—The use of nonlinear loads in the distribution system becomes a separate problem in increasing the spread of harmonics which can reduce power quality. The effect of placing a single tuned filter was investigated to minimize total active power losses and minimum %THDv against coordinated planning that had been carried out previously using the particle swarm optimization method by considering the distribution of validated harmonics on the IEEE 69 bus Test Standard System with the constrain specified. The effectiveness of the proposed plan can reduce total active power losses up to 59.61% and reduce the value of %THDv in each bus up to 55.18%.**

Keywords—Single Tuned Filter, Coordinated Planning, Particle Swarm Optimization, Harmonic, Power Quality.

I. INTRODUCTION

Increasing trend to utilized power electronic interfaced devices as nonlinear load is the main reason of the higher harmonic distortion level in modern power distribution systems [1]. Nonlinear loads are semiconductor devices that are easy to operate and control, but they can also cause the spread of harmonics that adversely lead to the equipment damage. According to IEEE Standard 519-2014, harmonics are defective waves due to distortion of a sinusoidal wave with a frequency multiple of integers from the fundamental frequency with a value of% THDv <5% [2-3].

The use of filters is one of the optimization techniques developed as an effective solution to reduce the spread of harmonics in a radial distribution system [4]. Several previous studies benefited from the use of active filters in mitigating the spread of harmonics. However, the use of single filters is still widely used because of easier implementation, low investment costs and easier maintenance. [5,6].

The effects of harmonic spread can be known using the Forward Backward Method (FBS) to find currents, voltages and power losses at fundamental frequencies [7]. In addition, the Harmonic Load Flow Method (HLF) is a method used to find currents, voltages and power losses for each harmonic order. The effect of current and voltage distortion is very large on the spread of harmonics in odd order harmonics due to the use of nonlinear loads. Therefore, proper and intelligent planning is needed to overcome it [8,9].

Utilization and development of renewable energy as an energy source provide the need for Distributed Generation (DG) based electrical energy which is considered capable of improving the voltage profile, reducing power losses and improving power quality in mitigating the harmonic spreads [10-12]. Capacitors as the reactive power compensation equipment are also considered capable in this regard but proper and strategic planning is needed in terms of improving power quality in mitigating the harmonic spreads because the resonance effect generated by improperly planned capacitors can make the system worse [13]. Network reconfiguration is an optimization technique which is also considered effective in minimizing power losses emerging in the distribution system by changing the network configuration by activating the tie switch after selecting the available sectional switch without any investment costs [14,15]. The system harmonic impedance value is affected by grid configuration and load pattern. it means that applying new configurations and load patterns may result in some changes in the index of power quality of the distribution systems [16]. Coordinated planning is a planning that coordinates several optimization techniques used to get objective functions. However, this is a complex matter in maintaining the quality of the system with the needs and increased of the existing load, especially the use semiconductor devices on both sides of household users, offices and industry [17,18].

In the previous study [17], coordinated planning for DG placement optimization, capacitor placement and reconfiguration simultaneously using PSO considering the use of nonlinear loads have been presented in several validated case studies. On the IEEE 33-bus system and IEEE 69-bus, there was a decrease in total losses by 67.89% and a decrease in the value of % of THDv. On the IEEE 69-bus system, there was a decrease in total losses by 39.62%, but the % THDv value system for some buses was outside the permitted limits. Optimization planning for the placement of a single tuned filter before and after DG placement gives better results to minimize active power losses in the radial distribution system, keeps the rms voltage with the prescribed limit, and decreases the total harmonic distortion level [19].

The kind practice of the distribution system is expected to be able to overcome power quality problems. Nonoptimal planning in finding the objective function can cause the system to be in a bad condition that it can even be damaged due to harmonic problems. Several artificial intelligence-based studies use the Adactive Bacterial Foraging Optimizations [6], PSO [19], WAO [20], NSGA-II [21], A Graph Search Algoritm [22] and ant colony methods [23]. This research is a continuation study of [17] in the optimal placement and sizing of the singed tuned filter to minimize total losses and % THDv which will be tested on the IEEE 69-bus radial distribution system using PSO method in several scenarios to get the better result on improving power quality.

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II. MODELING SYSTEM

A. Harmonic Power Flow

The Harmonic Load Flow Algorithm (HPF) was introduced by Teng [6]. The Backward sweep algorithm of harmonic load flow is used to obtain matrix $[A]$ representing the relationship between the branch current and injection current bus for h harmonic sequence. The forward sweep produces a $[HA]$ matrix representing the relationship between harmonic bus voltage and harmonic bus injection current. To find the current flowing from $i-j$ branch is used Backward sweep current equation;

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

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

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

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

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

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

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

$$\left|V_i^{(h),k+1} - V_i^{(h),k} \leq \varepsilon\right| \tag{6}$$

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

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

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

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

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

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

B. Single Tuned Filter

The harmonic filter is designed to suppress the amplitude of one or more frequencies of a voltage or current. With the installation of a harmonic filter on an electrical distribution network containing a harmonic source, the spread of harmonic current throughout it can be reduced. Furthermore, harmonic filters at fundamental frequencies can equal for the reactive power used to increase the power factor of the systems [4]. Single tuned filter is one of passive filters consisting of passive components that R, L and C in series. Single tuned filter is most widely used in industrial power systems in terms of overcoming harmonics [6]. This is because it is more efficient [19-23].

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 to fitness function evaluation, compares fitness particle evaluation with P_{best}, identifies particle result at best fitness value, updates position of particle and determines direction with best fitness on specified iteration [20].

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

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

$$f(x)_1 = \min P_{Loss} \tag{12}$$

- Minimal THDv

$$\%V_{THD,i} = \frac{V_{d,i}}{V_{rms,i}} * 100\% \tag{13}$$

$$f(x)_2 = \min \%V_{THD,i} \tag{14}$$

$$f(x) = f(x)_1 + f(x)_2 \tag{15}$$

B. Constrain

- Bus Voltage Limit

$$V_{min}(0.95\,pu) \leq V_{rms_i} \leq V_{max}(1.05\,pu) \tag{16}$$

- Total Harmonic Distortion Limit

$$THD_i(\%) \leq THD_{max} \tag{17}$$

C. Single Tuned Filter Design

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

- Step 1. Determine X_c and C on $f_{fundamental}$

$$X_c = \frac{V^2}{Q_{filter}} \tag{18}$$

$$C = \frac{1}{2\pi f X_c} \tag{19}$$

- Step 2. Specifies X_L and L at $f^{(h)}$

$$L = \frac{1}{C(2\pi f_{tun})^2} \tag{20}$$

$$X_L = 2\pi f L \tag{21}$$

- Step 3. Calculate the R value for Q quality

$$R = \frac{X_n}{Q} \tag{22}$$

$$X_n = \sqrt{\frac{L}{C}} \tag{23}$$

Then, we will get impedance from filter;

$$Z_{filter} = R + j(X_L - X_c) \tag{24}$$

Thus, the $f^{(h)}$ of the h impedance of the single tuned filter is;

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$$Z_{filter}^{(h)} = R^{(h)} + j\left(X_L^{(h)} - X_c^{(h)}\right) \qquad (25)$$

D. Optimization by PSO

Optimization in determining placement and sizing single tuned filter uses PSO. The steps of PSO are;

- Generated population of particle by position and velocity randomly in a search of dimension space
- Evaluating the fitness function of all particle
- Comparing evaluation of particle with P_{best}
- Updating *velocity* and *particle* position
- Back to step 2. If the criteria are met, it usually stops if the fitness value improves.

Parameters of PSO used are population = 100; iteration = 100; c_1 = 1; c_2 = 2. The step of reasearch carried out can be seen in Figure 2.

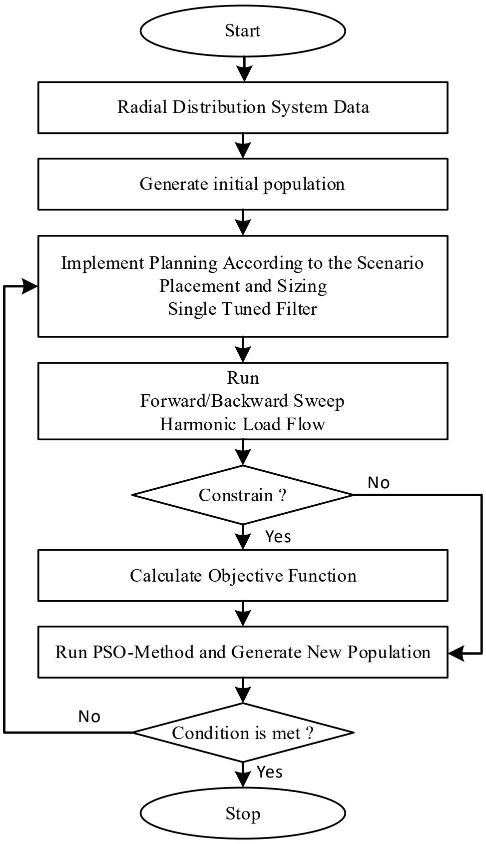

Fig 1. Step of the research.

E. IEEE 69-bus and Study Case

- IEEE 69-bus standard system.

  The Harmonic source will be injected on bus 6, 9, 14, 17, 22, 27, 33, 37, 40, 43, 49, 55, 61 and 69.

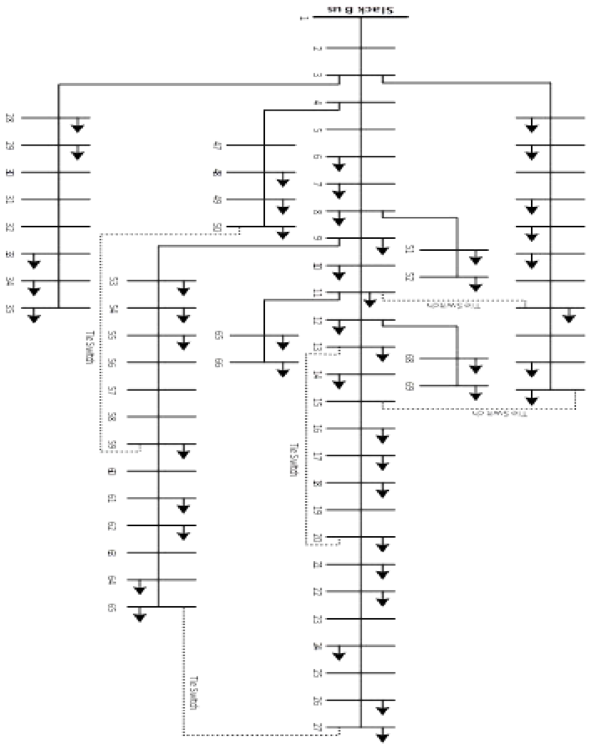

Fig 2. Single line diagram IEEE 69-bus system [15].

- Harmonic Source

  As for the value of the injection of harmonic currents from the use of nonlinear loads can generate the harmonic spreads in this research can be seen in Table 1. On bus 5, 7, 9, 11, 14, 17, 20, 24, 27, 29, 31 and 33 will be injected the harmonic source [17]

TABLE 1. INJECTION OF HARMONIC SOURCE IN LOAD BUS [17-19]

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

- Study Case

  To get the objective function on the constraints that have been determined in this study, it is simulated in several scenarios;

1) Scenario 1 (S-1). Normal Case
2) Scenario 2 (S-2). Optimal placement and sizing DG and capacitor bank with network reconfiguration simultaneously [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 simulation results of the proposed method through the MATLAB 2018B program tested on the IEEE 69-bus standard system are described in the following section.

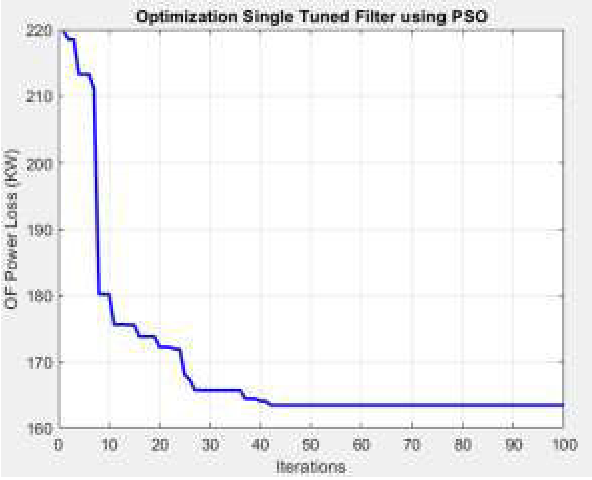

Fig 3. Iteration in Scenario 3.

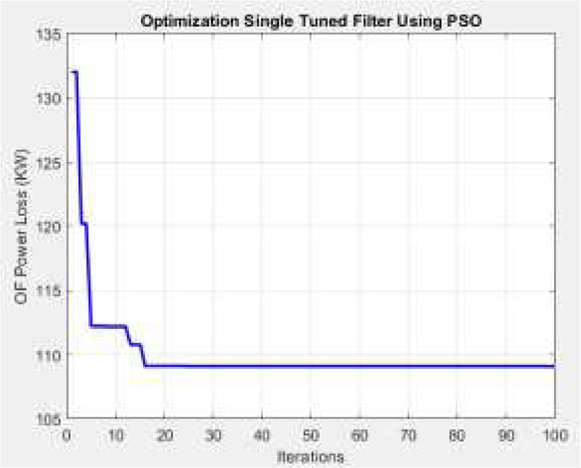

Fig 4. Iteration in Scenario 4.

The value of total power losses for fundamental and harmonic orders are calculated. The result of PSO is shown in Fig. 3-6. The optimum size of filter search by PSO is 1819,9 kVAr in bus 61 and converges in 42 iterations for S-3 and 1603,1 kVAr in bus 61 and converges in 16 iterations for S-4. The results of the placement and sizing of the single tuned filter in S-4 is faster than S-3. The iterations and the size of filter is smaller after determined by PSO. This is because the system that has been optimized in the previous research, which wasn't optimal for mitigating the harmonic spreads.

The result of analysis of harmonic load flow before and after optimization single tuned filter are shown in Table 2, Fig. 5-6. The Table 2 shows the comparison before and after optimization of active, reactive and total power losses in all scenarios under fundamental, total harmonic orders and total power losses. Figure 5 shows reduction of voltage level bus and Figure 6 shows reduction the harmonic spreads on %THDv value before and after optimization.

TABLE 2. COMPARISON OF POWER LOSSES BEFORE AND AFTER OPTIMIZATION IN IEEE 69-BUS

Condition	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	P_{Loss} (kW)	Q_{Loss} (kVAr)	P_{Loss} (kW)	Q_{Loss} (kVAr)	P_{Loss} (kW)	Q_{Loss} (kVAr)	P_{Loss} (kW)	Q_{Loss} (kVAr)
Fundamental	202.77	88.39	122.49	87.26	151.69	65.81	98.43	64.83
Harmonic	66.31	159.44	40.53	163.93	11.72	34.79	10.75	33.21
Total	270.05	248.32	163.04	251.21	`163.41	100.60	109.10	98.05

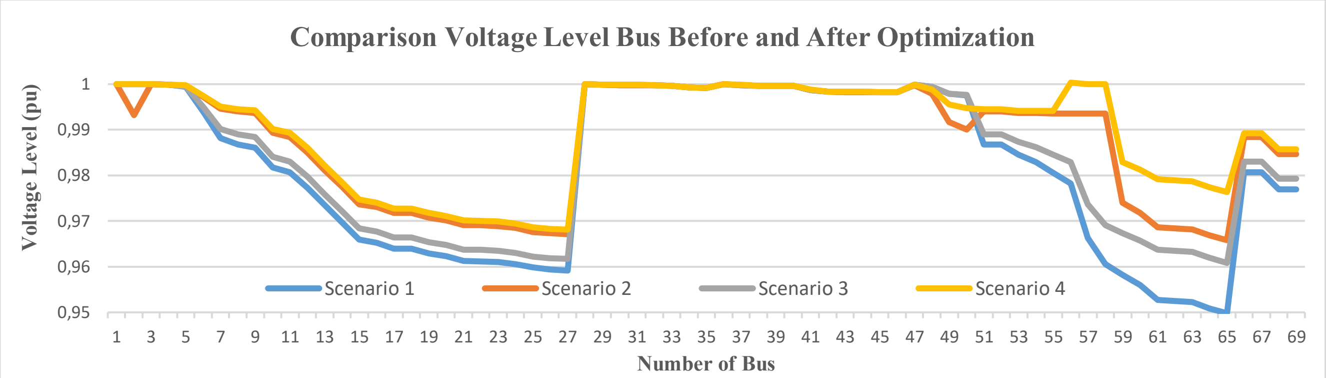

Fig 5. Comparison of voltage level bus before and after optimization in IEEE 69-bus.

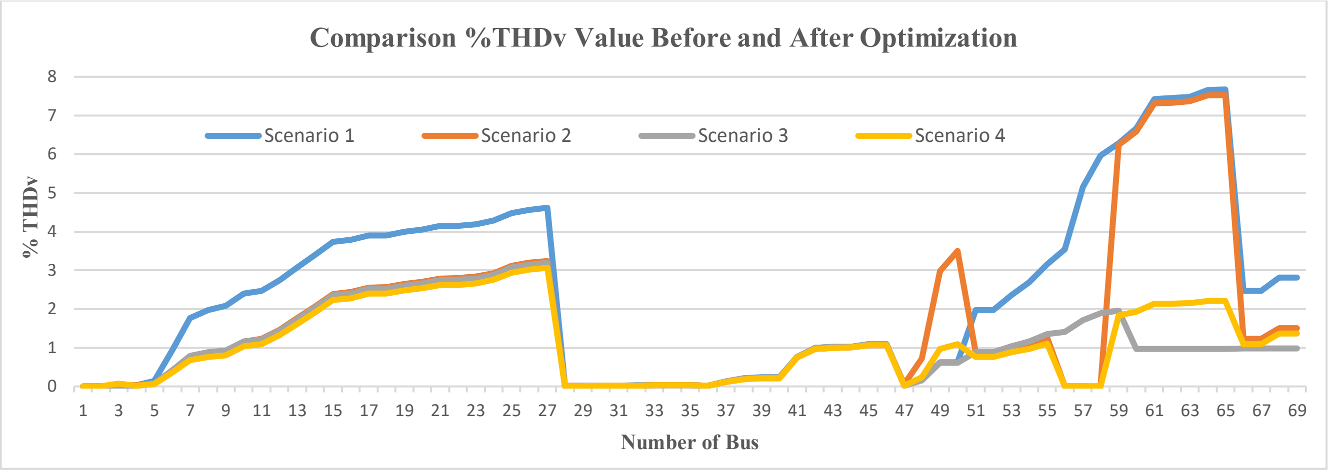

Fig 6. Comparison of %THDv bus before and after optimization in IEEE 69-bus

Table 2 shows the results in the form of decreasing the value of P_{Loss} after optimization. In S-3, it decreases from 270.05 kW to 163.41 kW or 39.48%. In S-4, it decreases from 163.04 kW to 109.1 kW or 33.08%. If scenario 4 is compared to the initial condition (scenario 1), the decrease in P_{Loss} is 160.95 kW or 59.61%.

Figure 5 shows the result in the form of an increase in voltage level (pu) for each bus S-3 and S-4. The best value of voltage level (pu) is in S-4. Figure 6 shows the results in the form of a decrease in average value of %THDv after optimization. In S-3, it decreases from 2.4834% to 1.1113% or 55.25%. In S-4, it decreases from 1.5794% to 1.1128% or 29.54%. if S-4 is compared with the initial condition (scenario 1), the decrease in the average value of %THDv is 1.3705% or 55.18%.

V. CONCLUSION

The use of PSO in optimization a placement and sizing single tuned filter aims to minimize total active power losses and the value of %THDv. It only takes 42 iterations in S-3 and 16 iterations in S-4 for PSO to find the best solution. The IEEE 69-bus radial distribution system is used to validate the result. The best result for test system is 1819.9 kVAr in bus 6 for S-3 and 1603,1 kVAr in bus 6 for S-4. The total P_{Loss} improvement is 23,46 % for S-3, 39.48% for S-4 and 59.61 for S-4 which is compared to initial conditions. The value of average %THDv was reduced by 55.25% for S-3, 29.54% for S-4 and 55.18% for S-4 which is compared to initial conditions. The better result in finding the objective function after optimization on systems that has been optimized previously in previous studies specially in mitigating the spread of harmonics. The next research will discuss the effect filter combination with other optimization techniques in unbalance three phase system for improving power quality.

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