PERFORMANCE ENHANCEMENT OF AN UNBALANCED AND HARMONICALLY DISTORTED THREE PHASE RADIAL DISTRIBUTION NETWORK BY OPTIMAL PLACEMENT OF CAPACITOR USING DSA

Committee Member:

Dr. Jai Govind Singh (chairperson)

Dr. Weerakorn Ongsakul

Dr. Shobhakar Dhakal

Presented By:

Happy Aprillia st115877 / 2212201012

Master Program
Energy FoS - Power System Engineering
School of Environment, Reseource and Development - Faculty of Industrial Technology
Asian Institute of Technoogy – Sepuluh Nopember Institute of Technology

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Outline of presentation

- Background and problem statement
- Objective of the study
- Scope and limitation of the study
- Literature review
- Methodology
- Result and Discussion
- Conclusions and Recommendation

Introduction

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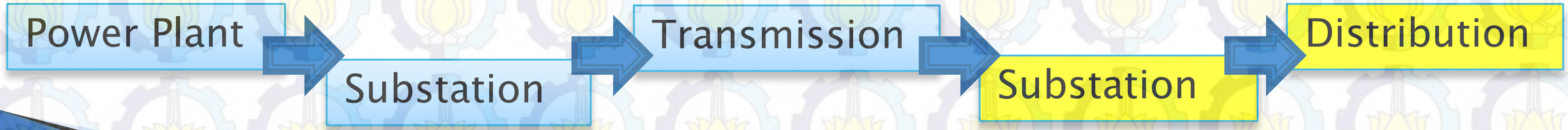
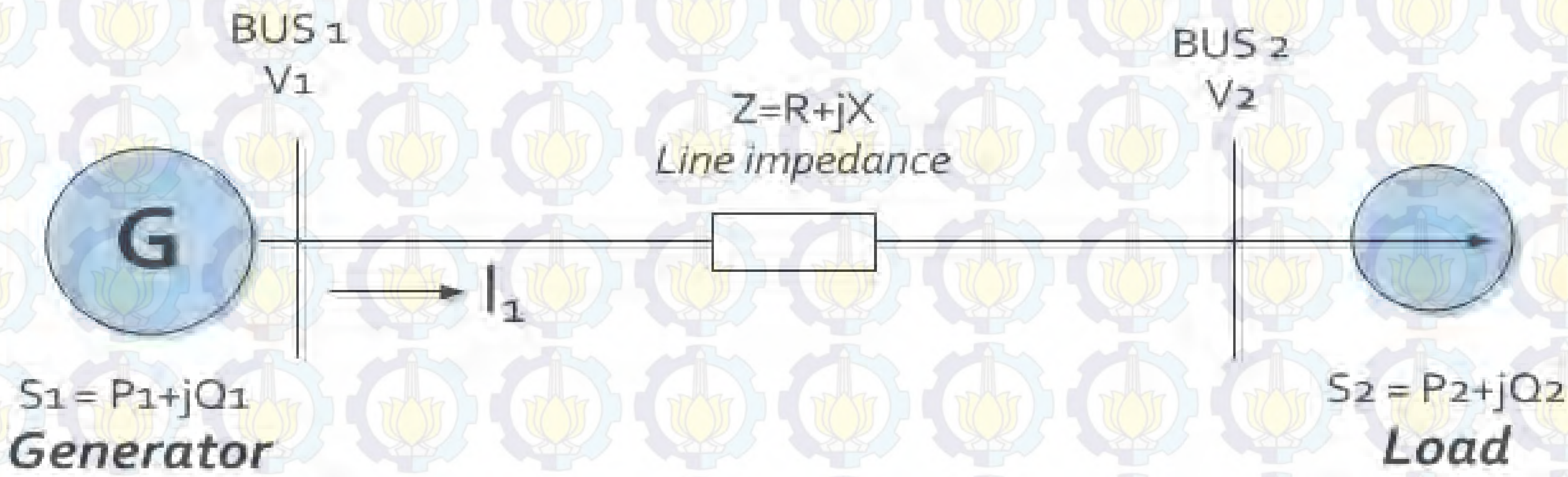


Introduction



$V = I.Z$

$V_2 = V_1 - V$

Voltage Drop → **Line Losses**

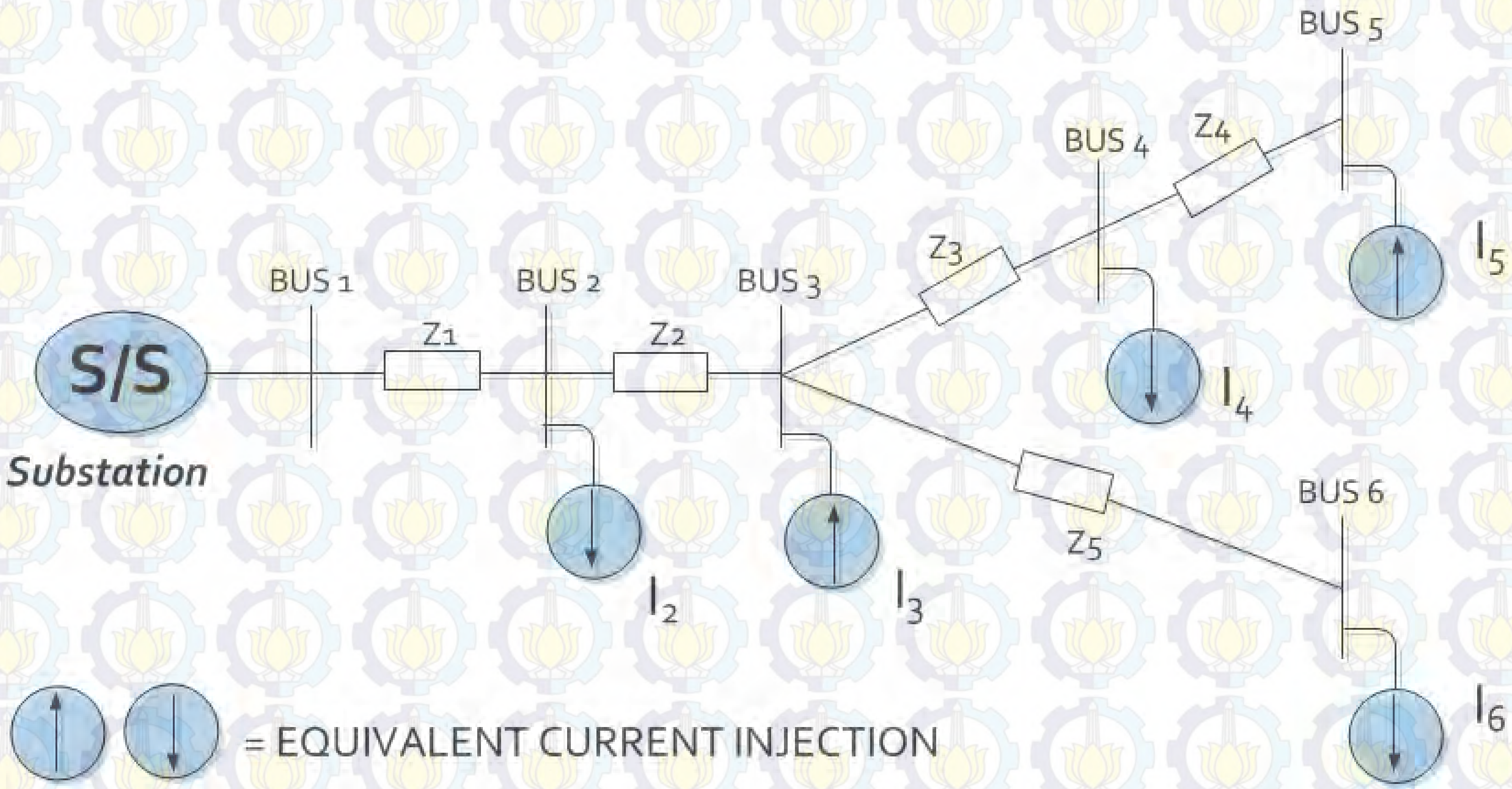
$P = V.I.\cos\phi$

$P = I^2.R$

Where,

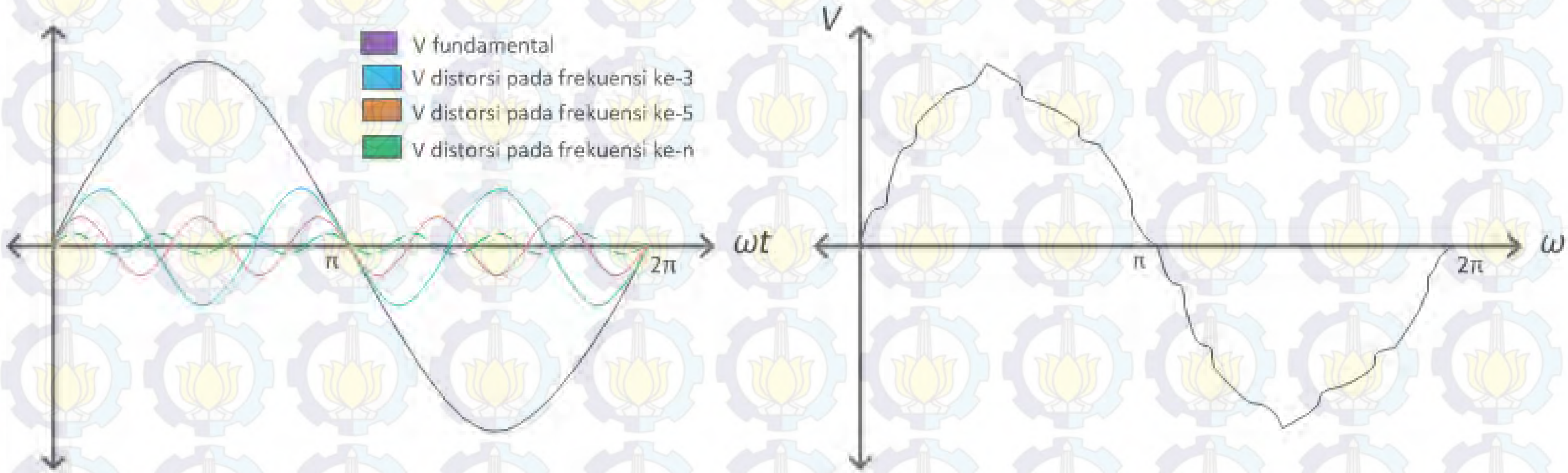
P = active power (Watt),
Q = reactive power (VAR),
V = voltage (Volt),
I = current (Ampere),
X = Reactance (ohm),
R = resistance (ohm).

Introduction



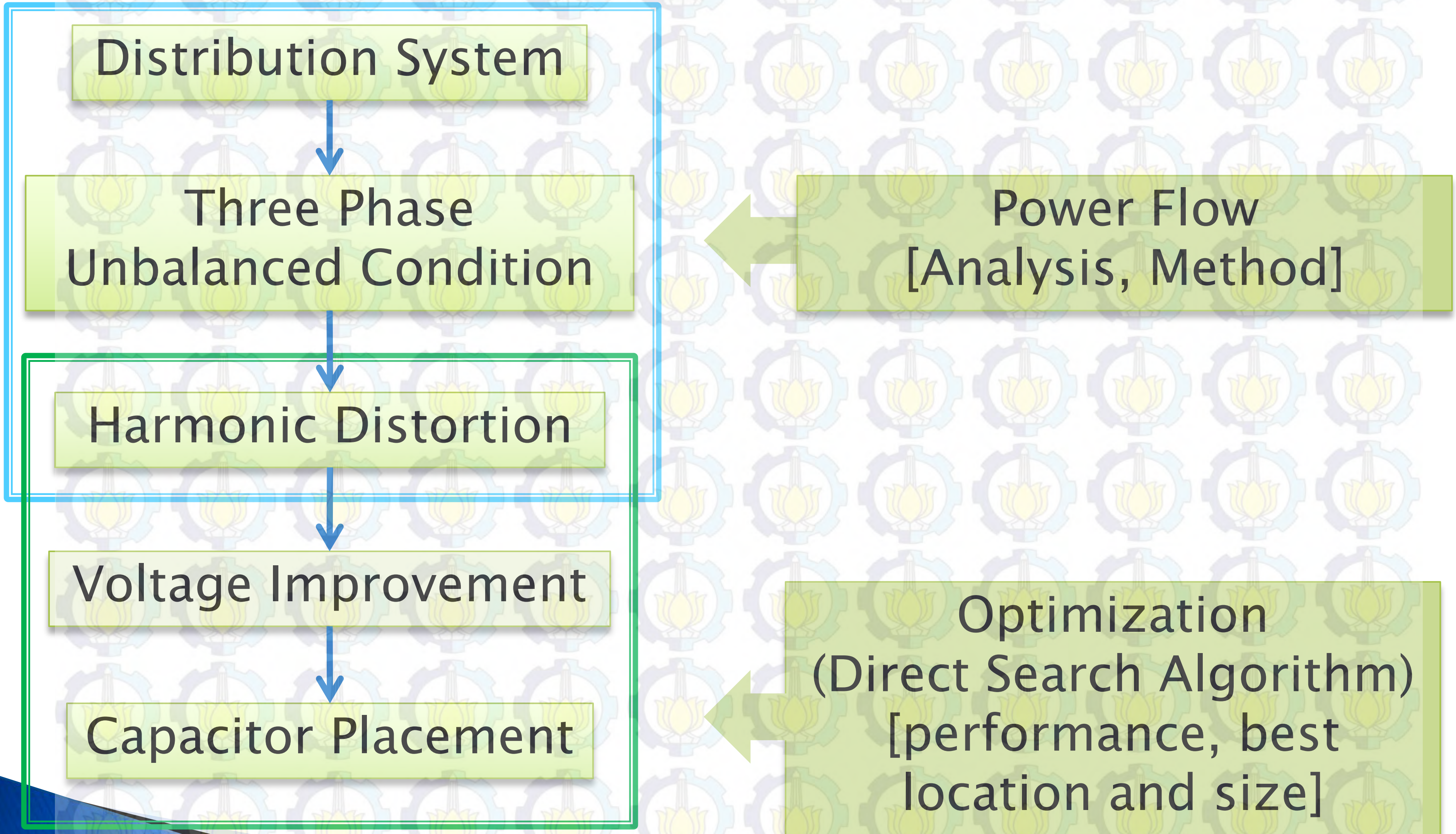
Introduction

- 519-1992 IEEE Standard of Harmonics Distortion



Bus Voltage at PCC	Individual Voltage Distortion (%)	THD (%)
69 kV and below	3,0	5,0
69,001 kV through 161 kV	1,5	2,5
161,001 kV and above	1,0	1,5

Statement of Problem



Objective of Study

Obtain appropriate harmonics distortion effects and voltage profile in distribution power system

Robust and fast three-phase power flow analysis application for unbalanced radial system.

Presents the analysis of the combination of three-phase power flow and power flow for investigate unbalanced radial system with harmonics distorted condition.

Knowing the optimal location and capacity of reactive power compensator with Direct Search Algorithm (DSA) in unbalanced radial harmonics distorted three phase system.

Scope and Limitation

1
- Harmonic source has been obtained from preliminary data (not through a reduction of the initial models)

2
- The harmonic power flow will only work as a passive power flow that can't handle an active operation like Distributed Generation effects in power system.

3
- Verification of the proposed method through the comparison of results between DSA and PSO

Literature Review

Literature Review

- (*Elamin, I.M., 1990)*:
  - The harmonic power by using Fast Decoupled method that applied to the loop scheme system (transmission system), not the radial system.
- *(J. H. Teng, 2000; Ulinuha, et al, 2007)*:
  - Method of Forward Backward (FB) can accommodate the high R/X ratio.
  - Has considered the placement of the reactive power compensator and effects of harmonics occurence
  - Requires a long time to calculate this replacement of forward/backward process.

Literature Review

- *(Eajal, A.A., El-Hawary, M.E., 2010)*:
  - application of Particle Swarm Optimization (PSO) to determine the location and capacity of reactive power
  - Consider harmonic distortion in the calculation algorithm
  - Succeeded in reducing the levels of harmonic distortion through placing capacitor in system.
- *(Syai`in, M., Lian K. L., Yang, N., Chen T., 2012):*
  - Network topology radial distribution approach
  - Requires only Bus-Injection Branch Current (BIBC) matrix and Branch Current to Bus Voltage (BCBV) matrix.
  - Does not consider the harmonic distortion effect.

Literature Review

- *(Singh and Rao, 2012):*
  - Allocating shunt capacitor based on the dynamic sensitivity factor and PSO to give the random initial size for the following location.
  - Having significant performance because it can determine both fixed capacitor or switch capacitor.
- *(El-Fergany, et al, 2014):*
  - Using load sensitivity factor and combination with system stability enhancement.
  - new approach for optimal capacitor placement and sizing using artificial bee colony
  - But, load sensitivity analysis does not give best result to identify prospective bus.

Literature Review

- *(Raju, M. Ramalinga, Murthy, K.V.S. Ramachandra, Ravindra, K., 2012):*
  - Optimization technique to determine capacitor installation using Direct Search Algorithm (DSA)
  - DSA is proven to minimize line losses better than PSO. This research proved that DSA algorithm has faster performance and high robustness on large scale systems than PSO
  - This research is not taking consideration of harmonic distortion in that research.

Literature Review

- *(Aman, M.M et al, 2014):*
  - Direct Search Algorithm is a heuristic method which is done according to the basic technical guideline which are developed based on experience in practical guidelines
  - Work fast and effective with the reduced searching space based on practical strategy.
  - Can be conducted by using sensitivity node, cost consideration, or voltage sensitivity index to obtain the objective.
  - Common approach to this algorithm is by using loss sensitivity analysis to identify the inital placement of the capacitor.

Methodology

Methodology

System Modelling

- Overhead Lines and Under Ground Cables
- Shunt Capacitors
- Three-Phase Transformer
- Loads

Power Flow

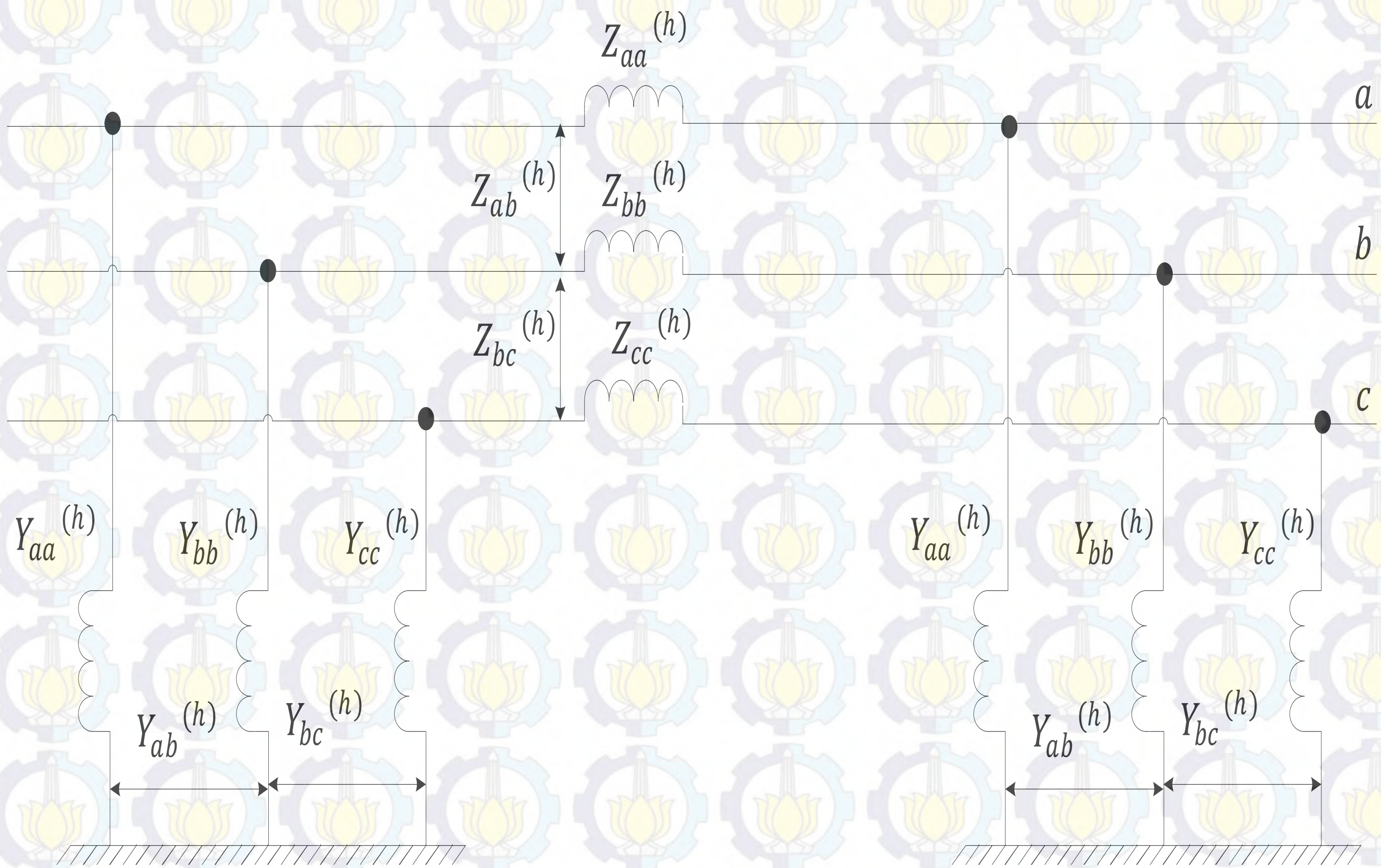
- Radial Distribution System
- Harmonic

Optimization

- Direct Search Algorithm

Methodology - System modelling

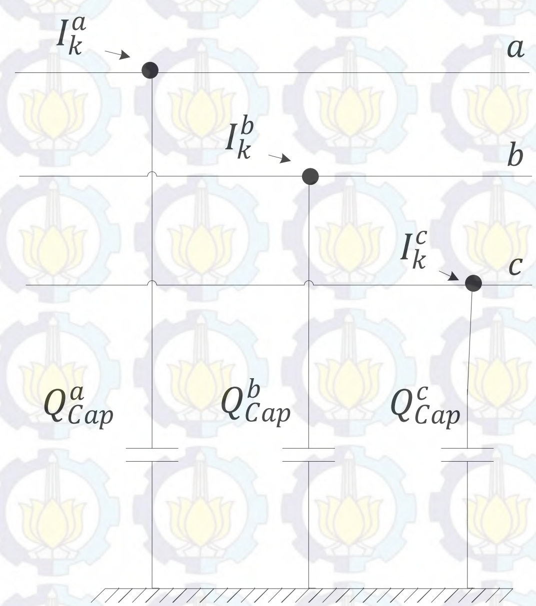
Overhead Lines and Under Ground Cables



Methodology – System Modelling

- Shunt Capacitors

$$X_{Cap}^{(h)} = \frac{{V_k}^2}{{Q_{Cap}}^{(h)}}$$

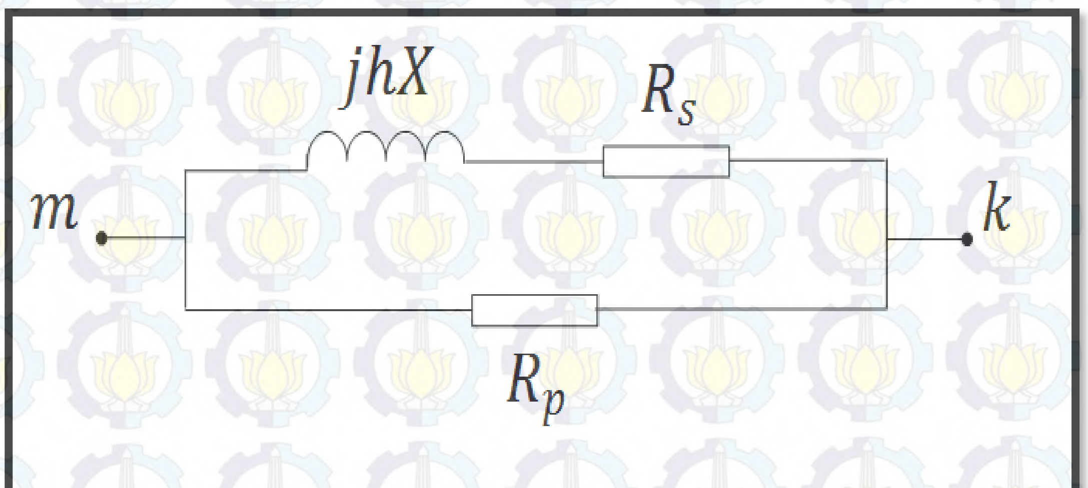


V_k = the nominal voltage
h = the harmonic order
Q_{Cap} = the capacitor reactive power injection

Methodology – System Modelling

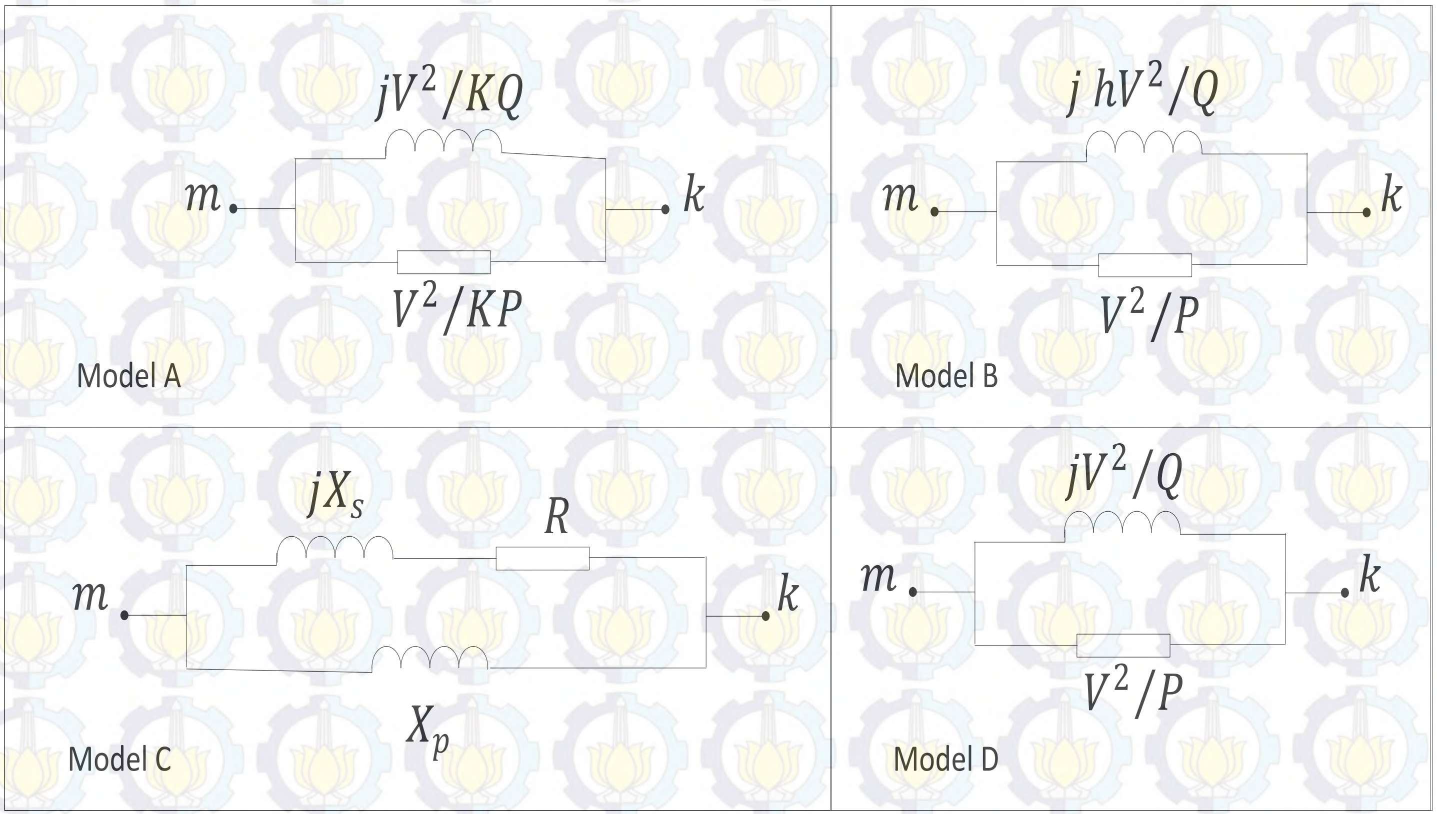
Three-Phase Transformer

- Power transformer impedances consist of:
  - leakage impedance : can be omitted from the transformer model when operating in normal conditions
  - magnetizing impedance : can always be included in the transformer model by a harmonic current source when operating in saturation conditions



Methodology – System Modelling

Linear Loads



Methodology – System Modelling

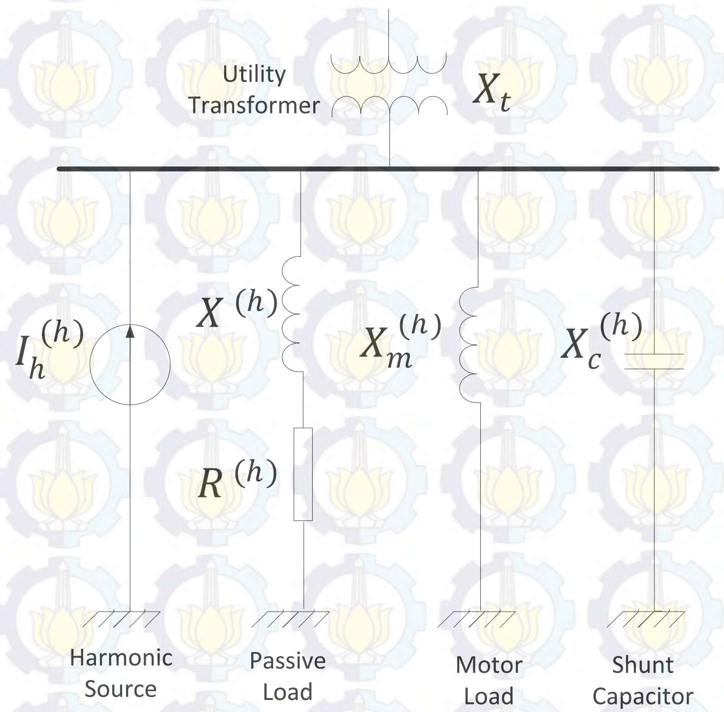
Nonlinear Loads

- The harmonic current magnitude:

$$I^{(h)} = I_{rated} \frac{I_{h-spectrum}}{I_{1-spectrum}}$$

Where,

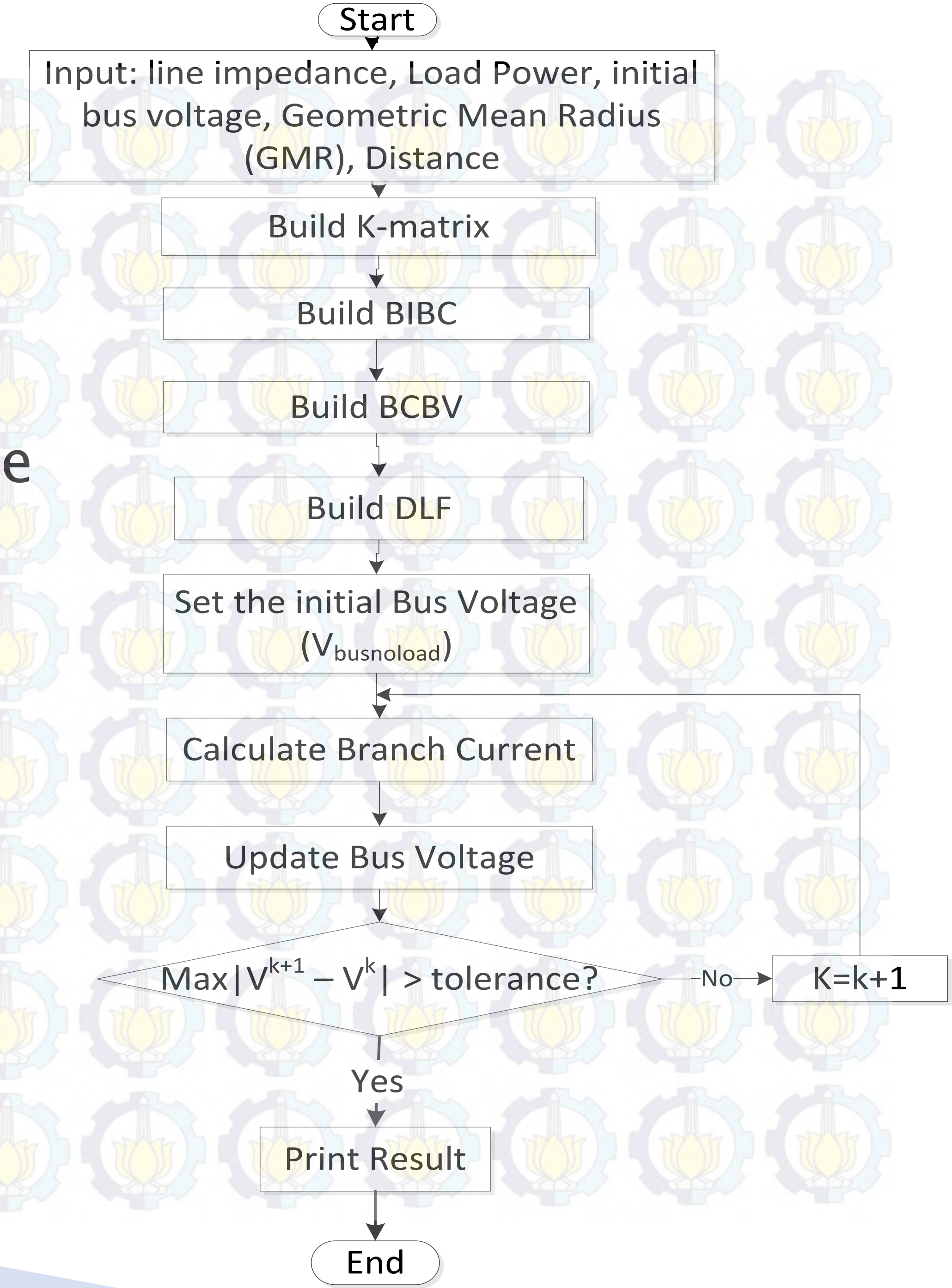
h-spectrum:the typical harmonic-producing load spectrum of the harmonic-producing loads.



Methodology
Harmonic Power Flow

First part of harmonic power flow yields :

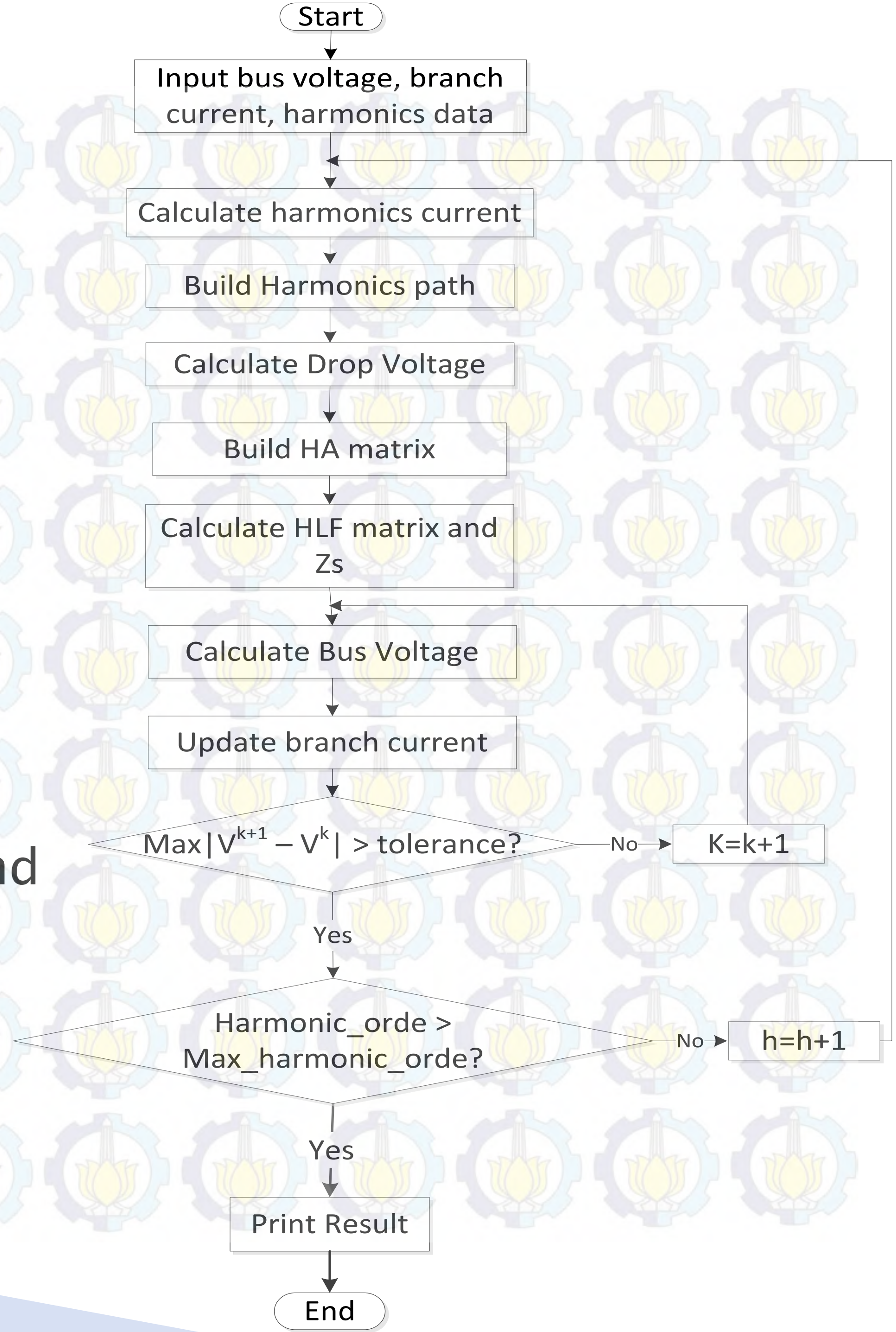
- magnitude and degree of bus voltage
- power loss in system



Methodology
Harmonic Power Flow

- Data requirement for harmonic power flow:
  - the harmonics current percentage at every orde of harmonic
  - transformer
  - bus voltage

- It will yield:
  - bus voltage in fundamental and harmonic frequencies at each bus.
  - THD
  - Harmonics current



Methodology -Constraints

1. Bus Voltage Limit

$$V_{min} < |V_i| < V_{max}$$

$$|V_i| = \sqrt{|V_i^{(1)}|^2 + \sum_{h=h_0}^{h_{max}} |V_i^{(h)}|^2}$$

V_{min}, V_{max} =lower, upper bound of bus voltage limit

$|V_i|$ =rms value of i-th bus voltage

i =1,2,..., number of buses

2. Total Harmonic Distortion

$$THD_{(i)}(\%) \leq THD_{max}$$

THD_{max} =maximum allowable harmonic distortion level at each bus

3. Number and Size of Shunt Capacitor

$$Q_{ci} \leq LQ_0, \quad L = 1,2,\ldots,n_c$$

$$\sum_{i=1}^{n_c} Q_{ci} \leq Q_T$$

Q_0 = smallest capacitor size available

Q_T = total reactive power demand

Methodology – Integration (DSA objective)

$$F = K_p P_{loss} + \sum_{i=1}^{n_{Cap}} K_{ci} Q_{ci} \quad (US\$)$$

Where,:

- K_p =Active power loss annual cost per unit (US$/kW/year)
- K_{ci} =Reactive power loss annual cost per unit at i-bus (US$/kVAR/year);
- Q_{ci} =Injected reactive power at i-bus (kVAR);
- n_{Cap} =total unit of reactive power installment;
- P_{loss} =total power loss (kW).

Methodology – Integration (DSA objective)

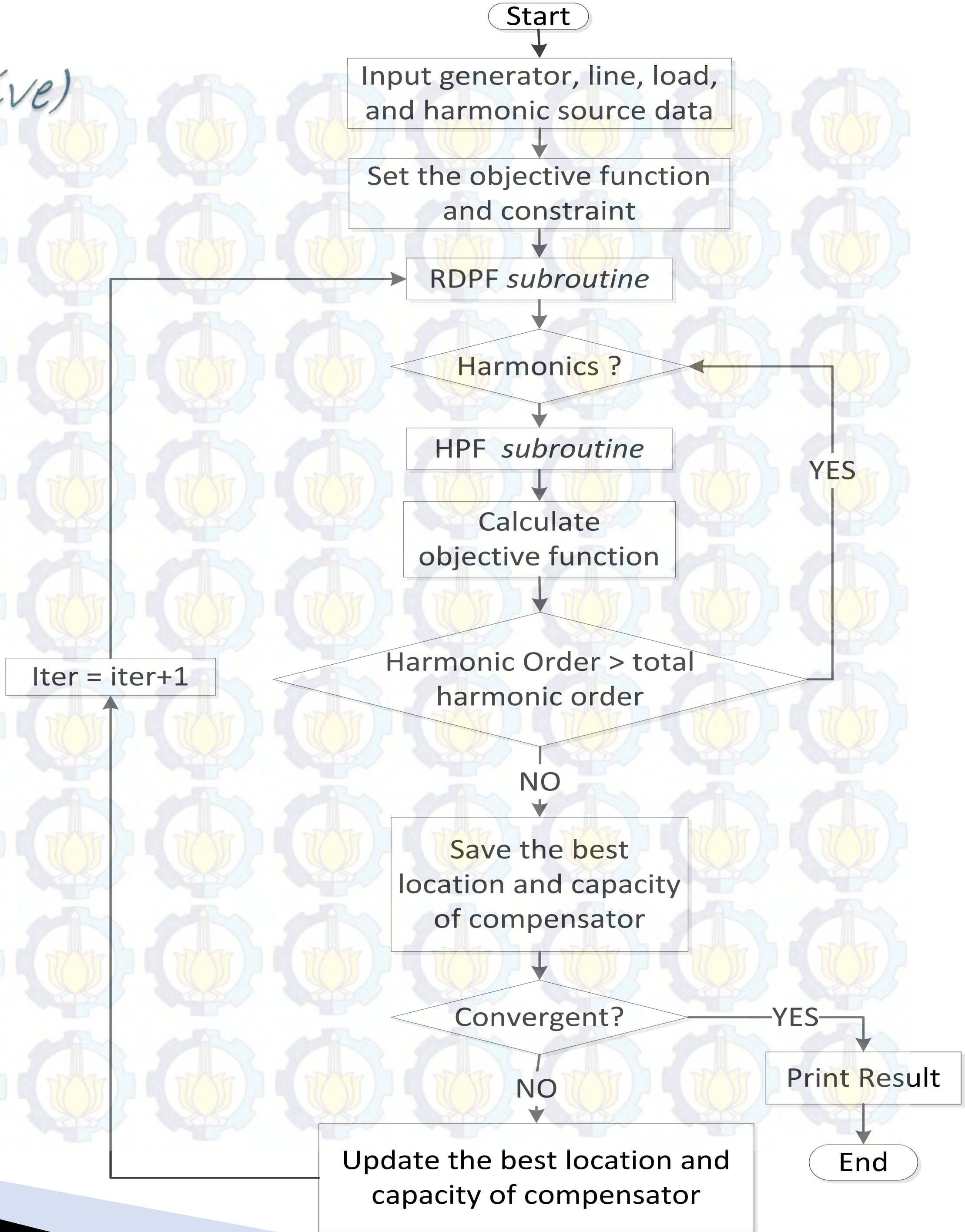
$$P_{loss} = \sum_{i=1}^{n_{branch}} P_{loss}^{(1)} + \sum_{i=1}^{n_{branch}} \sum_{h=h_0}^{hmax} P_{loss}^{(h)} \quad (kW)$$

Where,:

- P_{loss} = total power loss (kW)
- n_{branch} = number of branch
- h_0 = minimum orde of harmonic
- h_{max} = maximum orde of harmonic

Methodology
Integration (DSA objective)

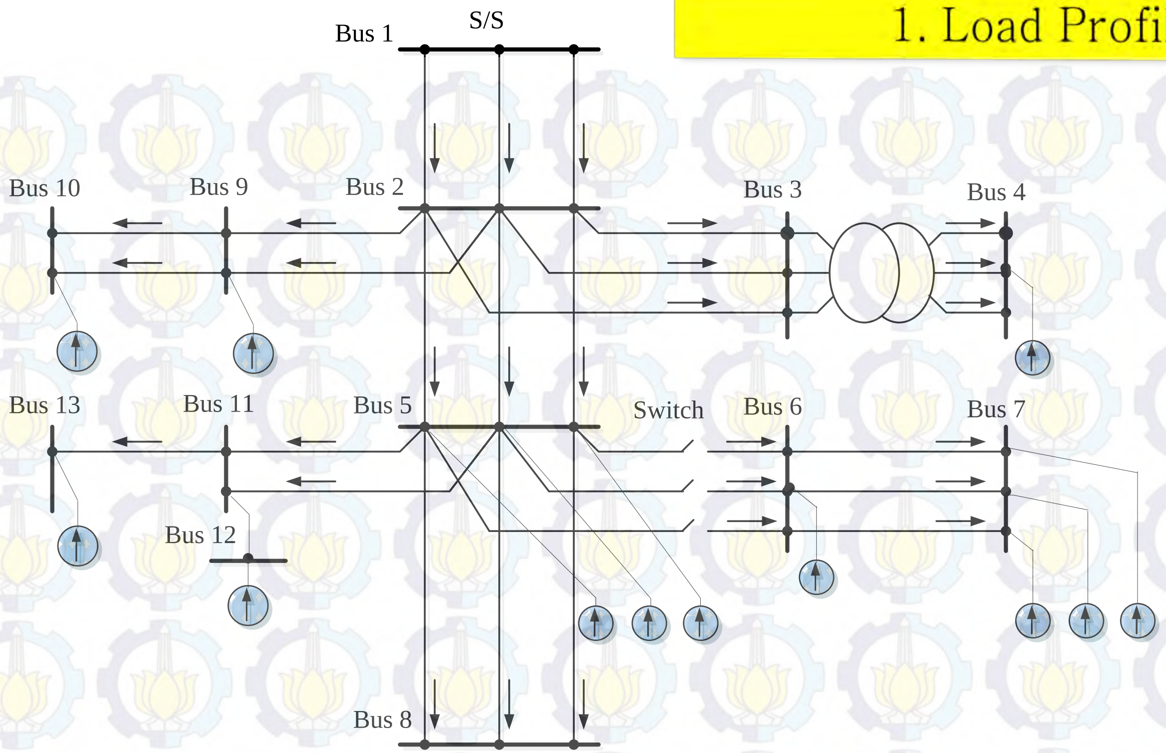
- Total losses
- THD level system, update for total loss system
- Enter data into the objective function is optimized and limitation are allowed.



Result & Discussion

Data Preparation

1. Load Profile at every bus

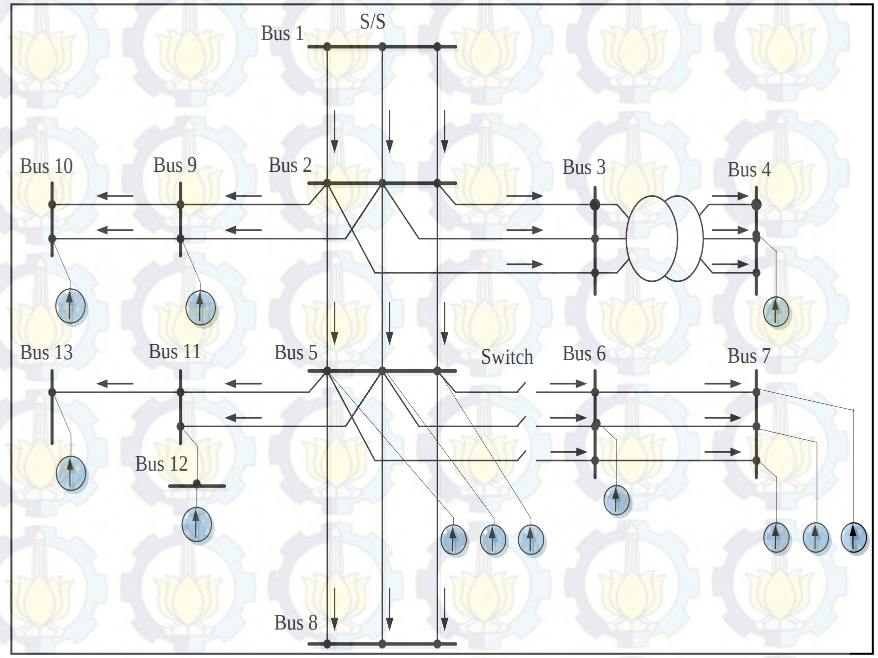


Test system IEEE 13-bus radial distribution system

```
%           Bus     --Load--            --Load--            --Load--
%                   Phase A             Phase B             Phase C
%           No    kW        kVAR      kW        kVAR      kW        kVAR
 loaddata = [  2    17        10        66        38        117       68        123
               3    0         0         0         0         0         0         123
               4    160       110       120       90        120       90        123
               5    222       127       222       127       222       127       123
               6    0         0         0         0         98        87        123
               7    485       190       68        60        29        212       123
               8    0         0         0         0         0         0         123
               9    0         0         170       125       0         0         123
              10    0         0         138       76        0         0         123
              11    0         0         0         0         0         0         123
              12    128       86        0         0         0         0         123
              13    0         0         0         0         170       80        123];
```

Harmonic Source Data

Node	Phase-A		Phase-B		Phase-C	
	kW	kVAR	kW	kVAR	kW	kVAR
4	42.63 Motor Passive	15 60% 40%				
5	383.7 Motors Flou. Passive	140.95 60% 30% 10%	383.7	140.95 60% 30% 10%	383.7	140.95 60% 30% 10%
6					170.53 Motors Flou. Passive Others	51.38 15% 15% 50% 20%
7	468.02 Motors Flou. Passive Others	189.07 15% 15% 50% 20%	468.02	189.07 15% 15% 50% 20%	468.02	189.07 15% 15% 50% 20%
9			170.53 Motors Flou. Passive Other	54 20% 20% 40% 20%		
10					230 Motors Flour. Passive Others	73 20% 20% 40% 20%
12	127.8 Motors Passive Flou. ASD	55.79 20% 60% 10% 10%				
13					170 Motors Flou. Passive Others	45 15% 15% 50% 20%
Total	1,040.25	400.8	622.44	255.5	1,244.14	522.98

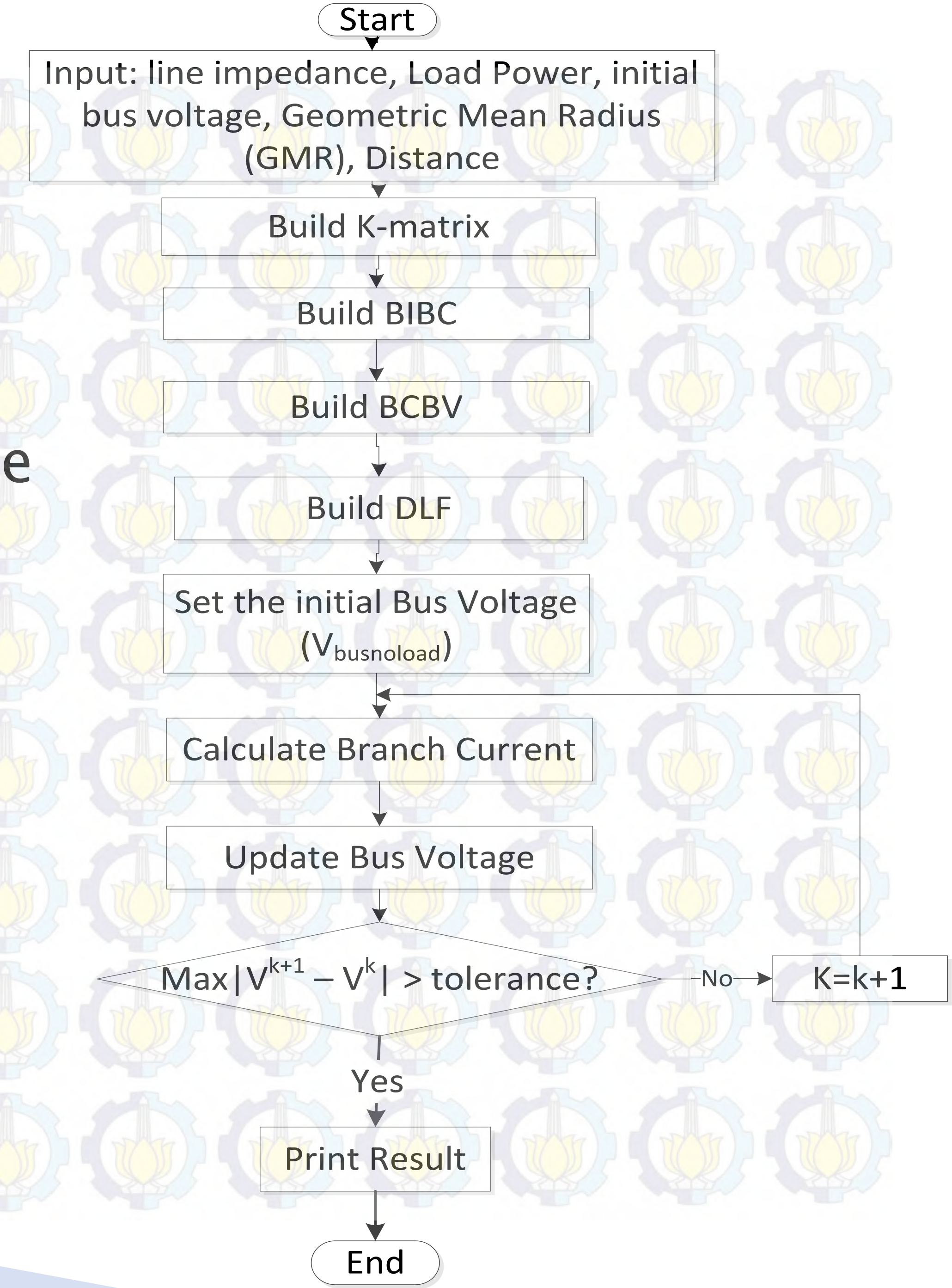


Three-phase Unbalance Radial System

Methodology
Distribution Power Flow

Distribution Power Flow yields :

- magnitude and degree of bus voltage
- power loss in system



4. Finding the Updated Current and Voltage

Current Profile

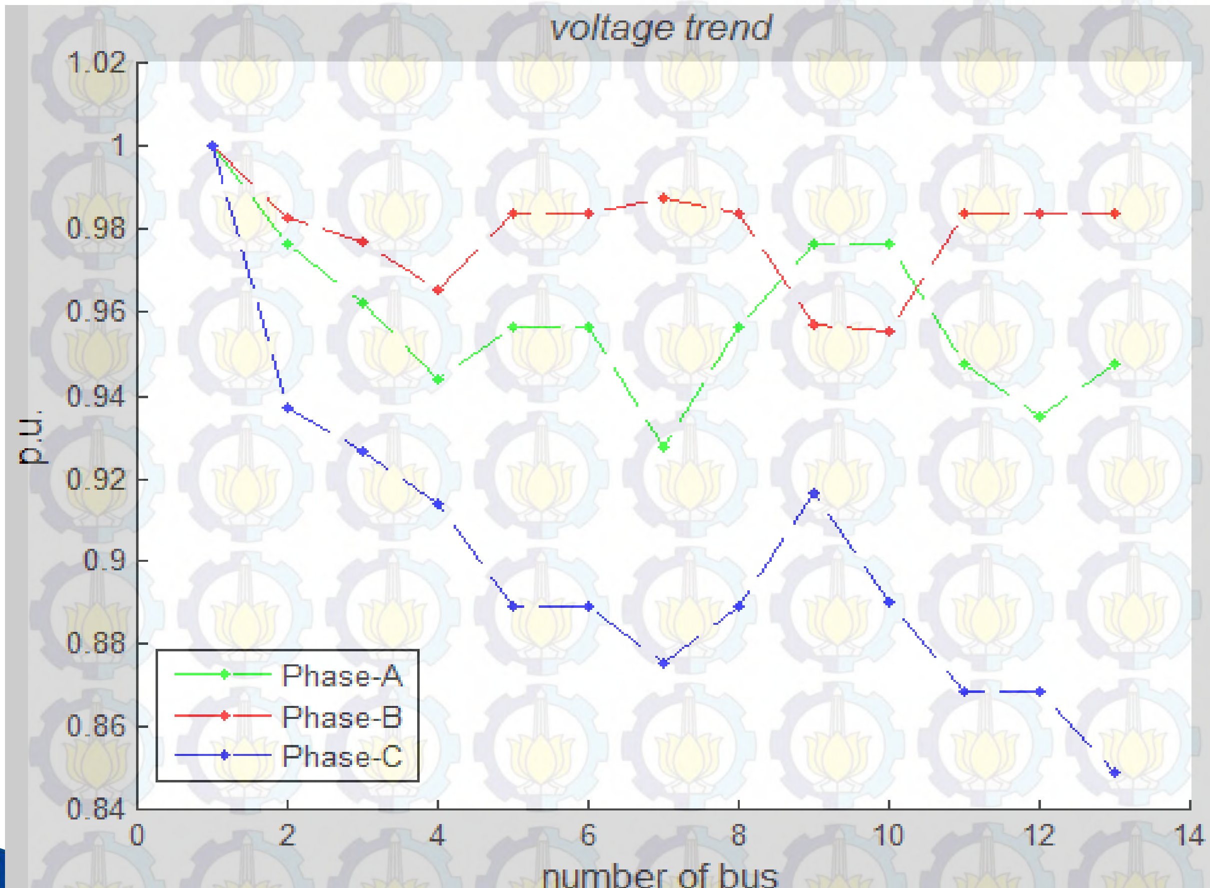
$$I_{bus(n_{bus})}^{(k)} = \left(\frac{P_{(n_{bus})}^{sh} + jQ_{(n_{bus})}^{sh}}{V_{Bus(n_{bus})}^{(k)}} \right)^*$$

Branch	Iteration = 1		Iteration = 19	
	Mag. (A)	Degree (∘)	Mag. (A)	Degree (∘)
1A	4.7411	-30.4655	5.1118	-33.7412
1B	18.3071	-149.9315	18.8664	-151.7691
1C	32.5302	89.8350	33.4336	88.1047
2A	0	0	0	0
2B	0	0	0	0
2C	0	0	0	0
3A	46.6742	-34.5085	5.1231	-38.2144
3B	36.0577	-156.8699	37.2992	-158.8616
3C	36.0577	83.1301	37.2105	81.1925
4A	61.4807	-29.7727	66.5131	-33.0009
4B	61.4807	-149.7727	6.5011	-152.3117
4C	61.4807	90.2273	64.5171	87.8118
5A	0	0	0	0
5B	0	0	0	0
5C	31.5014	78.4028	33.3862	75.9341
6A	125.2136	-21.3929	139.4609	-26.1601
6B	21.7996	-161.4237	23.9006	-164.3622
6C	51.4361	37.7893	54.5837	34.9364
7A	0	0	0	0
7B	0	0	0	0
7C	0	0	0	0
8A	0	0	0	0
8B	50.7234	-156.3268	52.7617	-158.6027
8C	0	0	0	0
9A	0	0	0	0
9B	37.8711	-148.8427	39.5083	-151.0478
9C	0	0	0	0
10A	0	0	0	0
10B	0	0	0	0
10C	0	0	0	0
11A	37.0691	-33.8962	40.9362	-37.3629
11B	0	0	0	0
11C	0	0	0	0
12A	0	0	0	0
12B	0	0	0	0
12C	45.1642	94.7989	47.6046	92.1342

4. Finding the Updated Current and Voltage

Voltage Profile

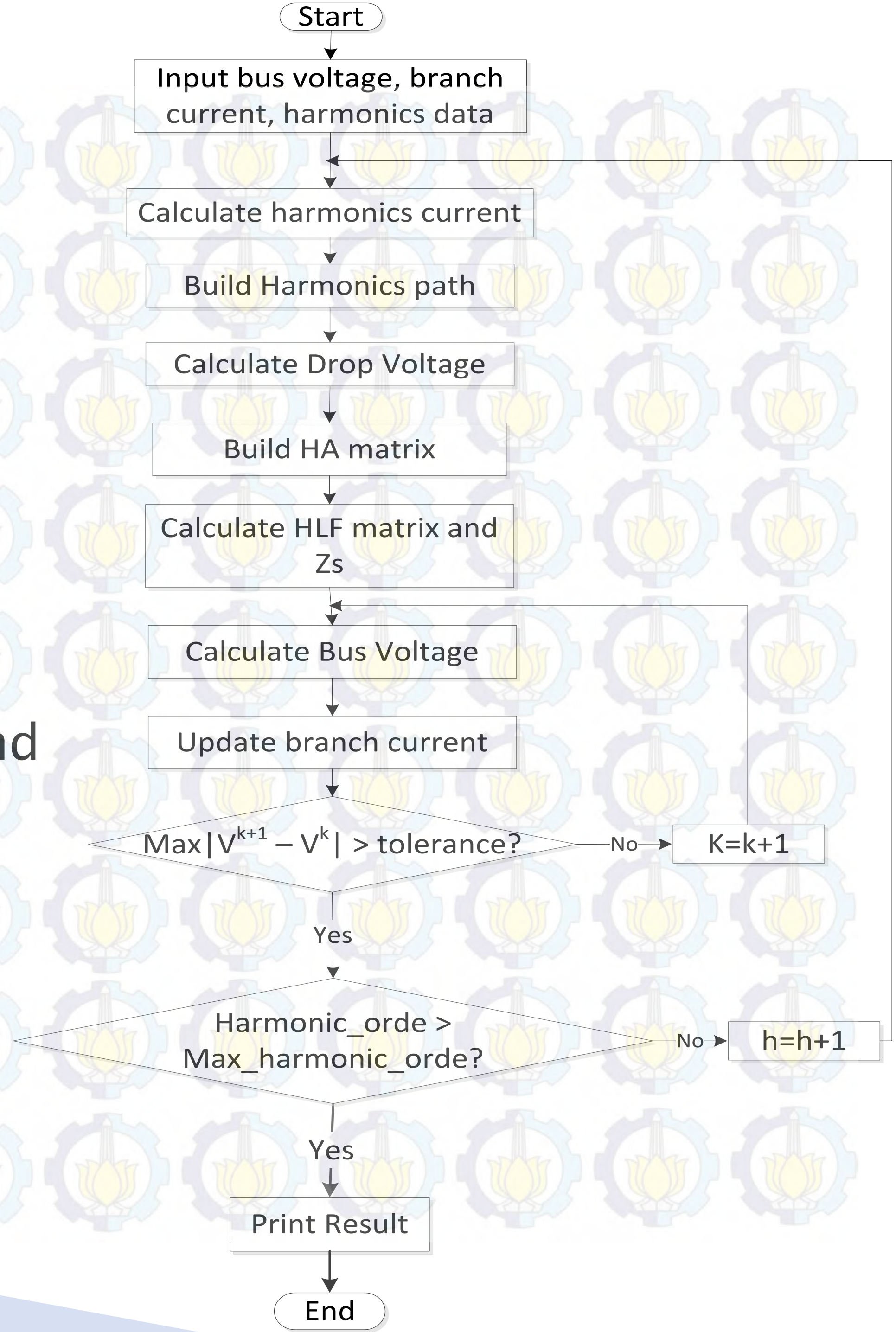
$$V_{Bus}^{(k+1)} = V_{bus_{noload}} - \Delta V_{Bus}^{(k)}$$



- Base Voltage: 4.16 kV
- Voltage is separated by 0^0, -120^0, and 120^0 due to the phase-A, phase-B and phase-C

Methodology
Harmonic Power Flow

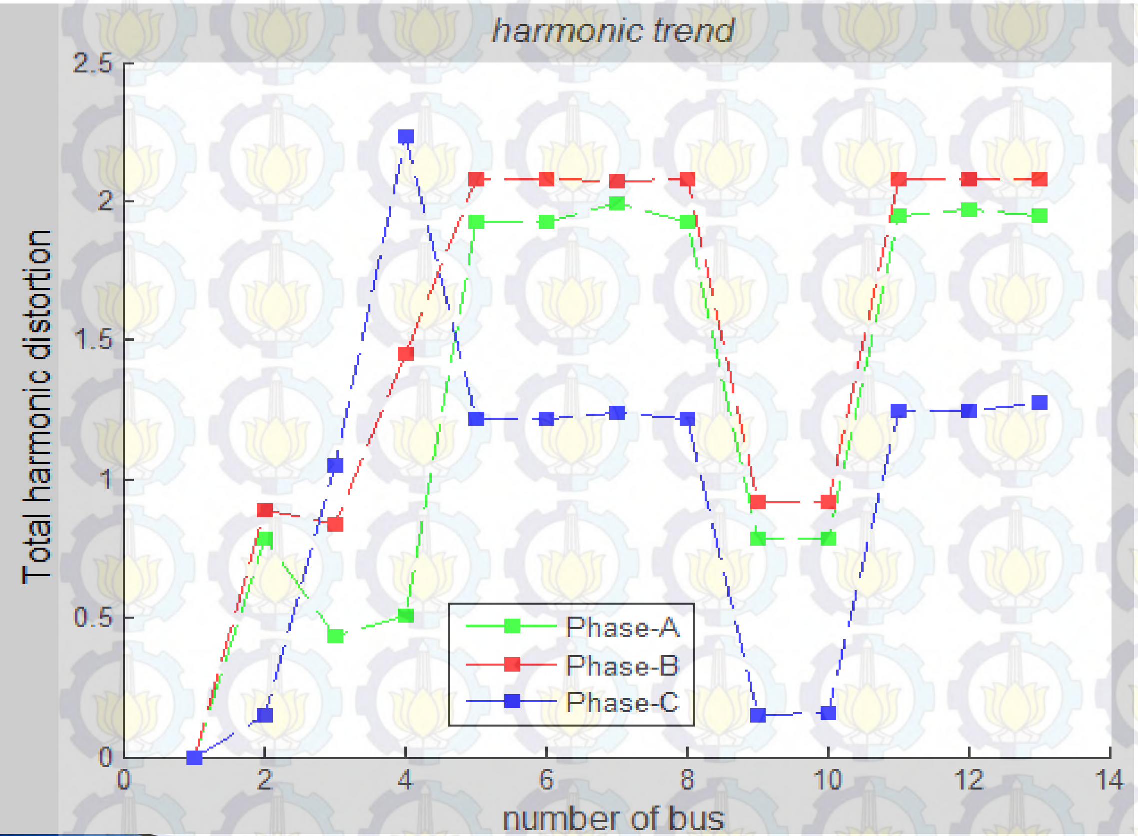
- HPF requires specific data
  - the harmonics current percentage at every orde of harmonic
  - transformer
  - bus voltage
- HPF yields:
  - bus voltage in fundamental and harmonic frequencies at each bus.
  - THD
  - Harmonics current



5. Finding Total Harmonic Distortion Voltage Level and Harmonic Power Loss

$$V_{n_{bus}}^{(h)} = HA \times I_{n_{bus}}^{(h)}$$

THD in Voltage



Harmonic Injected Current

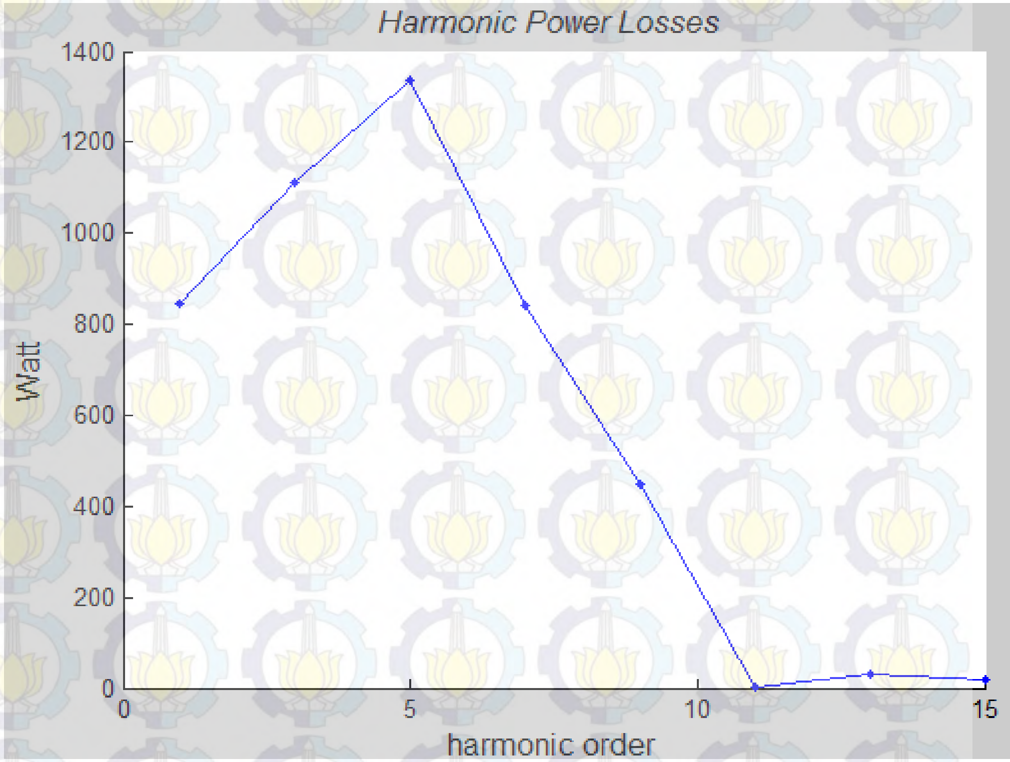
Iteration = 1			
Branch	Mag. (uA)	Branch	Mag. (uA)
1A	0.0441	7A	0.0441
1B	0.0424	7B	0.0416
1C	0.0286	7C	0.0315
2A	0.0441	8A	0.0441
2B	0.0424	8B	0.1022
2C	0.0286	8C	0.0196
3A	0.0441	9A	0.0441
3B	0.0424	9B	0.1044
3C	0.0286	9C	0.0249
4A	0.0441	10A	0.0918
4B	0.0416	10B	0.0416
4C	0.0315	10C	0.0335
5A	0.0441	11A	0.0918
5B	0.0416	11B	0.0416
5C	0.0315	11C	0.0335
6A	0.0441	12A	0.0918
6B	0.0416	12B	0.0416
6C	0.0315	12C	0.0335

5. Finding Total Harmonic Distortion Voltage Level and Harmonic Power Loss

Harmonic Power Loss

$$F = \boxed{K_p P_{loss}} + \sum_{i=1}^{n_{Cap}} K_{ci} Q_{ci} \quad (US\$)$$

$$P_{loss} = \sum_{i=1}^{n_{branch}} P_{loss}^{(1)} + \boxed{\sum_{i=1}^{n_{branch}} \sum_{h=h_0}^{hmax} P_{loss}^{(h)}} \quad (kW)$$



$$\boxed{\sum_{h=1}^{harmonic\_orde} \left[\sum_{j=1}^{nbus} \sum_{m=1}^{nbus} Vj^{(h)}.Vm^{(h)}.Yjm^{(h)} \cos(\theta j^{(h)} - \theta m^{(h)} - \delta jm^{(h)})\right]}$$

System after Load Flow – Reference

$$S_{total-updated} = \sum_{i=2}^{nbus} P_i + jQ_i$$

$$\cos \emptyset_{total-updated} = \frac{P_{update}}{\sqrt{P_{update}{}^2 + Q_{update}{}^2}}$$

Total Power Losses

$$S_{total-losses} = \sum_{j=1}^{n_{branch}} S_{losses-j} = \sum_{j=1}^{n_{branch}} \Delta V_j \; x \; I_j{}^*$$

Active Power Loss Cost = 168 US$/kW

GENERATION				
kW	1,238.429	762.277	1,116.986	3,117.692
kVAR	529.503	609.675	456.203	1,595.380
kVA	1,346.878	976.099	1.206.557	3,529.533
PF	0.919	0.781	0.926	
LOAD				
kW	1,055.000	809.000	1,247.000	3,111.000
kVAR	508.000	533.000	702.000	1,743.000
kVA	1,170.935	968.798	1,431.018	3,570.751
PF	0.901	0.835	0.871	
LOSSES				
kW	91.715	23.361	65.007	180.083
kVAR	10.751	38.338	122.899	171.987
kVA	92.342	44.895	139.032	276.270
TOTAL LOSSES (US$)= 30,253.944				
*** with losses price=168 USD/kW/year				

capacity refference of total capacitor

power losses

Total losses in US$ which is calculated from :
Power losses * 168 US$/kW

Capacitor Installation Approach with Direct Search Algorithm

Capacitor Installation Approach

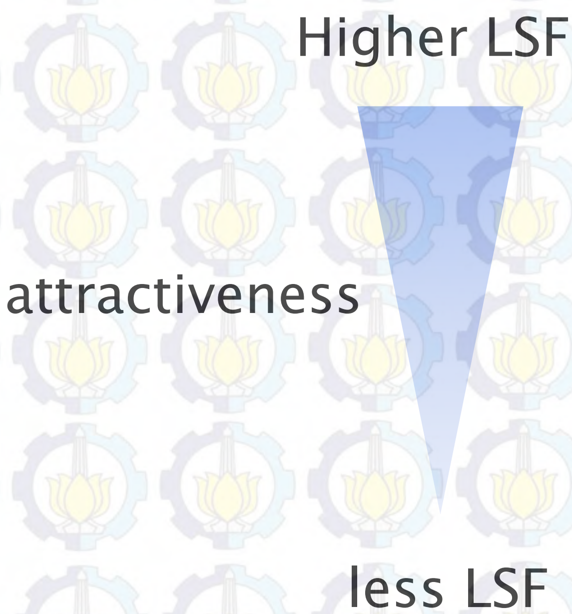
1. Direct search algorithm with load sensitivity factor
   a. Single Size Capacitor Installation
   b. Maximum Size of Capacitor Installation
2. Direct search algorithm with LSF-based Random prediction

- For those strategy, the references will be as follows:
  - Total cost of active power losses = 30,253.944 USD/year
  - Active power losses = 180.083 kW
  - Maximum reactive power limit = 1,743 kVAR
  - Maximum THD level = 5 %

Load Sensitivity Factor

$$LSF - aggre =$$

$$\frac{\partial P_j^{(h)}}{\partial Q_j^{(h)}} = \frac{2 \times Q_j^{(h)} \times R_k^{(h)}}{V_j^{(h)}}$$



Branch		phase	LSF - aggregated
11	12	1	4,32
9	10	2	4,13
6	7	1	3,69
6	7	2	3,55
1	2	1	2,53
2	5	1	2,51
5	6	1	2,51
5	8	1	2,51
2	3	1	2,50
5	11	1	2,50
3	4	1	2,47
1	2	2	1,83
2	5	2	1,82
5	6	2	1,82
5	8	2	1,82
2	3	2	1,79
2	9	2	1,79
3	4	2	1,75
5	11	3	0,81
2	5	3	0,79

1a. Single Size Capacitor Installation

- By the LSF got in previous

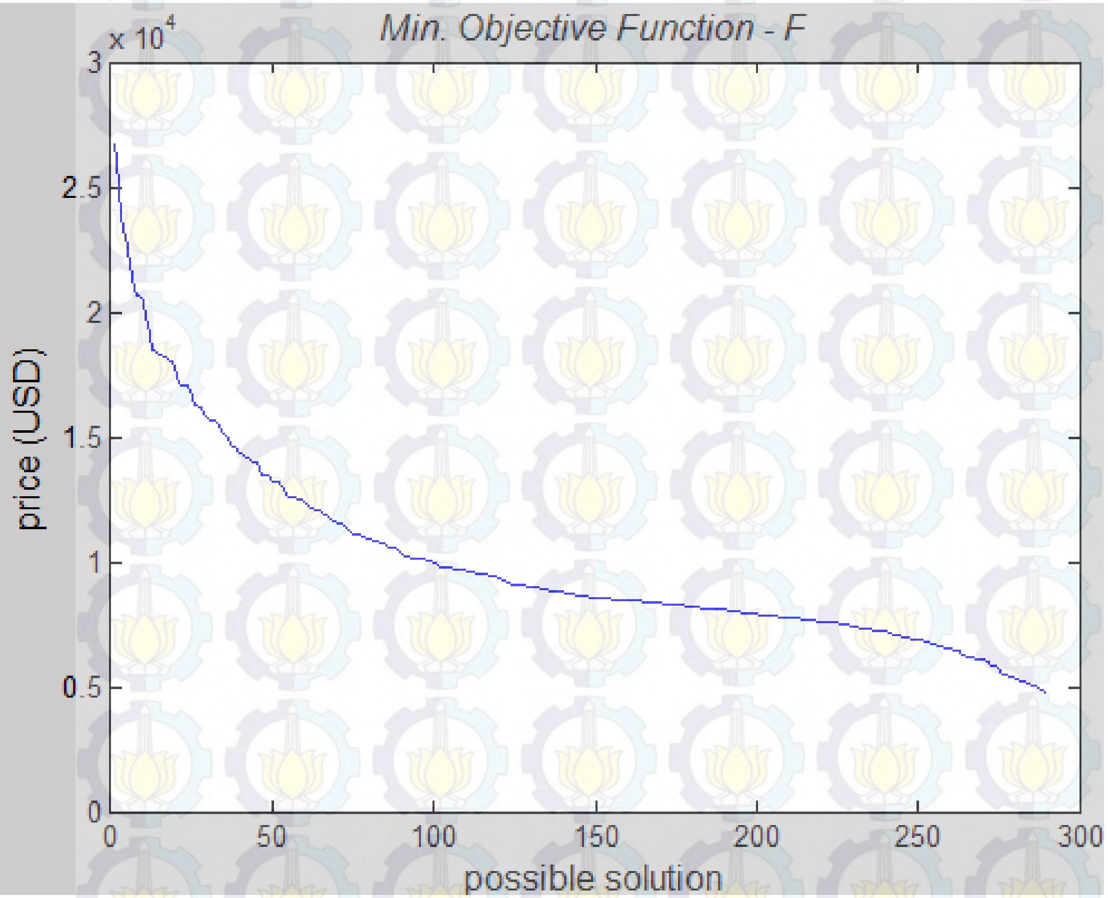
- The total prospective buses are 29 locations
- Total searching space will be 29x10=290 trial
- From the LSF, the order of capacitor placement will be as the following picture

```
% send_bus recieve_bus phase LSF by aggregated
  11    12    1    4.3245
   9    10    2    4.1257
   6     7    1    3.6947
   6     7    2    3.5505
   1     2    1    2.5302
   2     5    1    2.5141
   5     6    1    2.5141
  ...   ...  ....   ....
   9    10    3    0.29
```

Result of Single Size Capacitor Installation

Capacitor_Size	Location	Active_PLoss_kW	Losses_Price_USD	Vmax - Vmin
150	12 - 1	46.881	7876.052	0.986 - 0.838
150	10 - 2	47.721	8017.163	0.998 - 0.849
150	7 - 1	44.530	7481.080	0.988 - 0.842
150	7 - 2	49.795	8365.577	1.010 - 0.848
150	2 - 1	49.725	8353.740	0.987 - 0.846
150	5 - 1	47.473	7975.529	0.986 - 0.842
150	6 - 1	49.316	8285.095	0.986 - 0.842
150	8 - 1	49.091	8247.324	0.986 - 0.842
150	3 - 1	49.270	8277.353	0.987 - 0.845
150	11 - 1	48.567	8159.260	0.986 - 0.838
150	4 - 1	46.654	7837.792	0.987 - 0.845
150	2 - 2	49.672	8344.942	0.998 - 0.849
150	5 - 2	50.909	8552.683	1.007 - 0.848
150	6 - 2	48.994	8230.943	1.007 - 0.848
150	8 - 2	48.550	8156.387	1.011 - 0.848
150	3 - 2	48.888	8213.135	0.998 - 0.849
150	9 - 2	51.115	8587.255	0.998 - 0.849
150	4 - 2	50.381	8464.078	0.998 - 0.849
150	11 - 3	50.407	8468.458	0.981 - 0.885
150	5 - 3	45.399	7626.952	0.981 - 0.872
150	6 - 3	48.317	8117.228	0.981 - 0.872
150	8 - 3	50.571	8495.871	0.981 - 0.872
150	9 - 3	50.313	8452.636	0.985 - 0.860
150	4 - 3	46.915	7881.638	0.985 - 0.861
150	2 - 3	49.679	8346.099	0.985 - 0.860
150	3 - 3	50.405	8468.112	0.985 - 0.861
150	7 - 3	42.944	7214.646	0.980 - 0.872
150	13 - 3	43.098	7240.457	0.981 - 0.897
150	10 - 3	42.677	7169.800	0.985 - 0.860
300	12 - 1	40.736	6843.569	1.008 - 0.826
...				
1500	10 - 3	97.344	16353.713	1.155 - 0.858

Result of Optimal Capacitor Placing and Location with LSF-Aggregated 1x900 kVAR at bus-8 phase-A



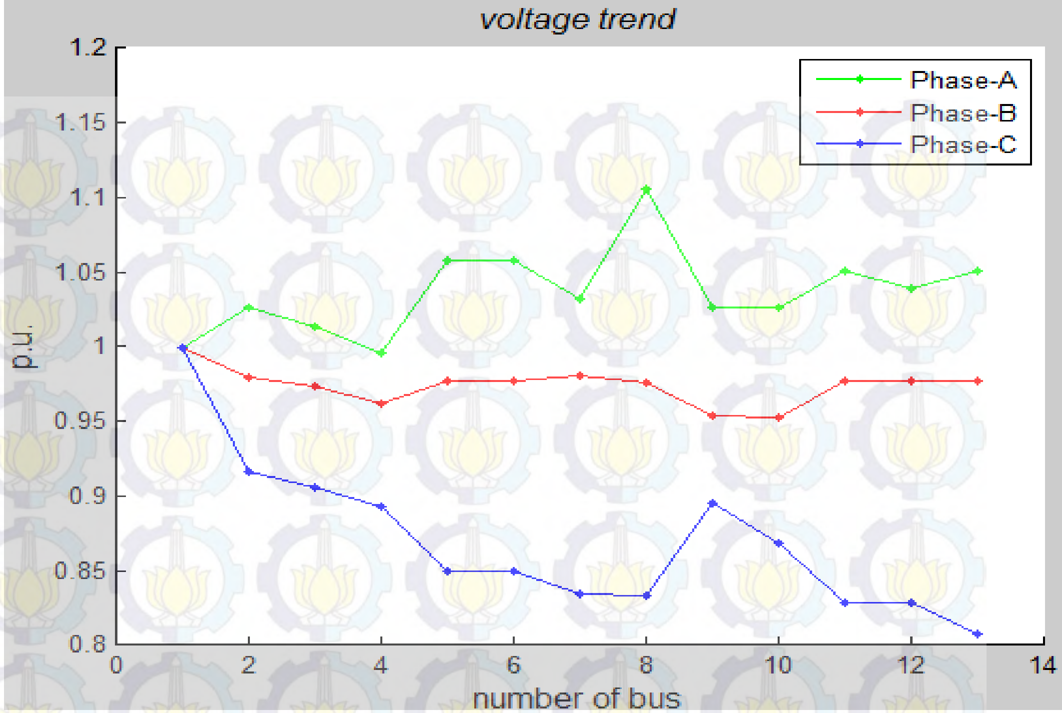
min_obj_all_find =
4.6901e+003 -→ 4,690 USD/year

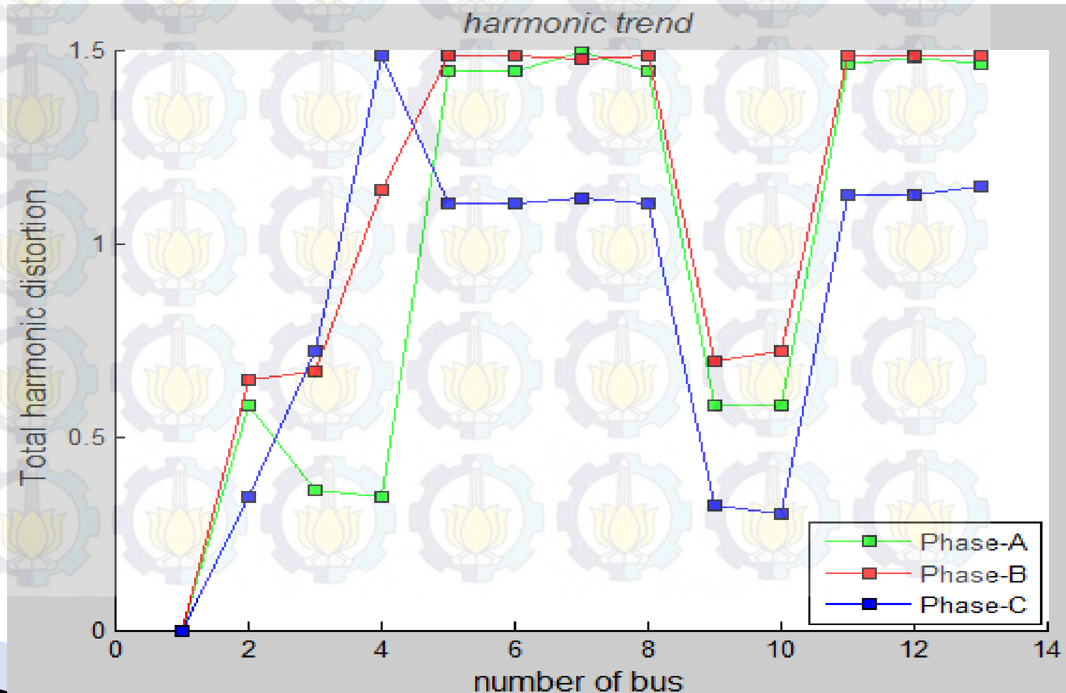
Best Size	= 900
Best Location	= 8 (1)
Max Voltage	= 1.106
Min Voltage	= 0.808
Max THD	= 1.642
Min THD	= 0.273
RealPowerLoss	= 26.937

Result of Optimal Capacitor Placing and Location with LSF-Aggregated

900 kVAR at bus-8 phase-A

- Bus-13 phase-C has the lowest voltage
- Bus-8 phase-A has the highest voltage
- The voltage condition is not within the standard.
- Recent harmonic profile are significantly within the limit.
- THD level can comply with the constraint, which is not exceeding 5 %.

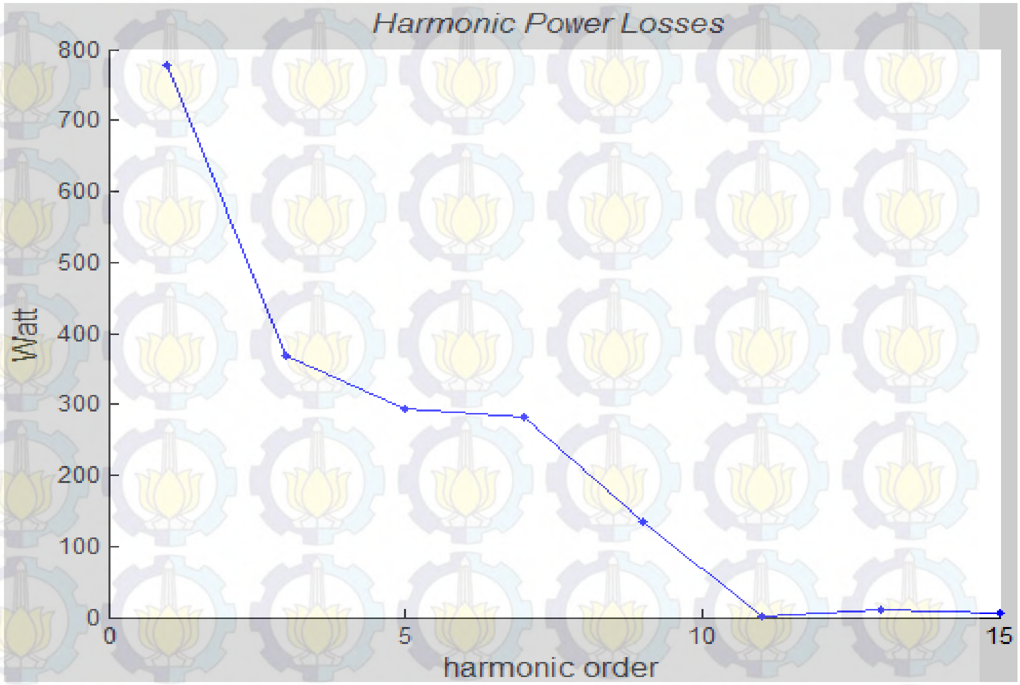


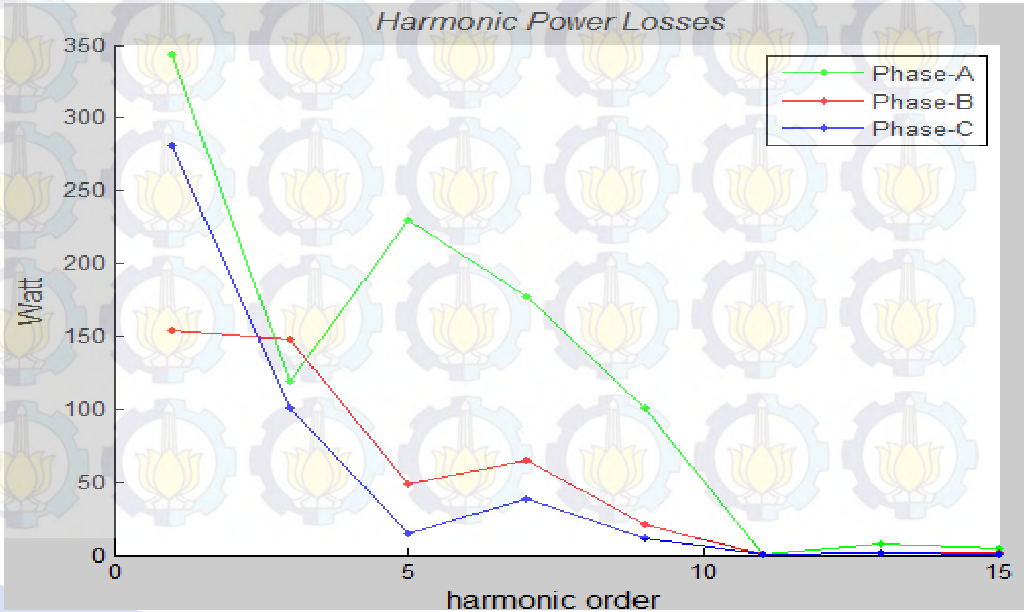


Result of Optimal Capacitor Placing and Location with LSF-Aggregated

900 kVAR at bus-8 phase-A

- power losses are significantly decreasing in comparison with the base case system.
- power losses in second last order of harmonic are very small
- By placing 900 kVAR at bus-8 phase-A, the harmonic penetration is reduced by half
- The harmonic penetration in phase-A are still high because it is loaded by more harmonic loads.





1b. Maximum Size Capacitor Installation with voltage constraint

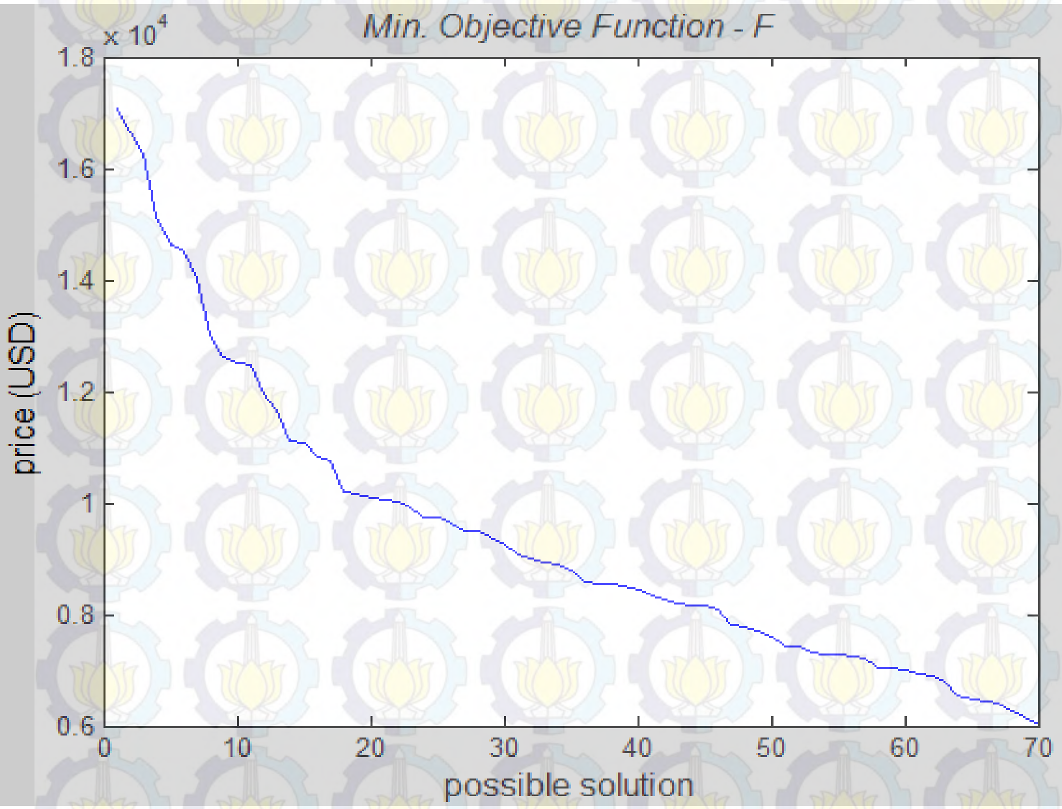
- By the LSF got in previous, the focus will be on poor voltage profile, then
  - The total prospective buses are 7 locations
  - Total searching space will be 7x10=70 trial
  - The order of capacitor placement will be as the following picture

```
% send_bus recieve_bus phase LSF by aggregated
5   11  3   0.8688   8.0860
2   5   3   0.8894   7.9351
5   6   3   0.8894   7.9351
5   8   3   0.8894   7.9351
6   7   3   0.8754   4.5126
11  13  3   0.8492   4.0141
9   10  3   0.8900   2.9284
```

Result of Single Size Capacitor Installation

Capacitor_Size	Location	Active_PLoss_kW	Losses_Price_USD	Vmax - Vmin
150	11 - 3	50.407	8468.458	0.981 - 0.885
150	5 - 3	45.399	7626.952	0.981 - 0.872
150	6 - 3	48.317	8117.228	0.981 - 0.872
150	8 - 3	50.571	8495.871	0.981 - 0.872
150	7 - 3	42.944	7214.646	0.980 - 0.872
150	13 - 3	43.098	7240.457	0.981 - 0.897
150	10 - 3	42.677	7169.800	0.985 - 0.860
300	11 - 3	51.654	8677.881	0.977 - 0.912
300	5 - 3	42.256	7098.942	0.977 - 0.894
300	6 - 3	47.846	8038.141	0.977 - 0.894
300	8 - 3	52.592	8835.437	0.977 - 0.893
300	7 - 3	37.539	6306.538	0.976 - 0.894
300	13 - 3	37.833	6355.950	0.977 - 0.912
300	10 - 3	36.663	6159.398	0.982 - 0.871
....				
1500	11 - 3	56.199	9441.436	1.132 - 0.925
1500	5 - 3	51.192	8600.283	1.070 - 0.916
1500	6 - 3	72.636	12202.920	1.070 - 0.916
1500	8 - 3	95.062	15970.407	1.136 - 0.903
1500	7 - 3	48.361	8124.676	1.086 - 0.907
1500	13 - 3	99.863	16776.963	1.180 - 0.927
1500	10 - 3	97.344	16353.713	1.155 - 0.858

Result of Optimal Capacitor Placing and Location with LSF-Aggregated 3x150 kVAR at bus-7 phase-C

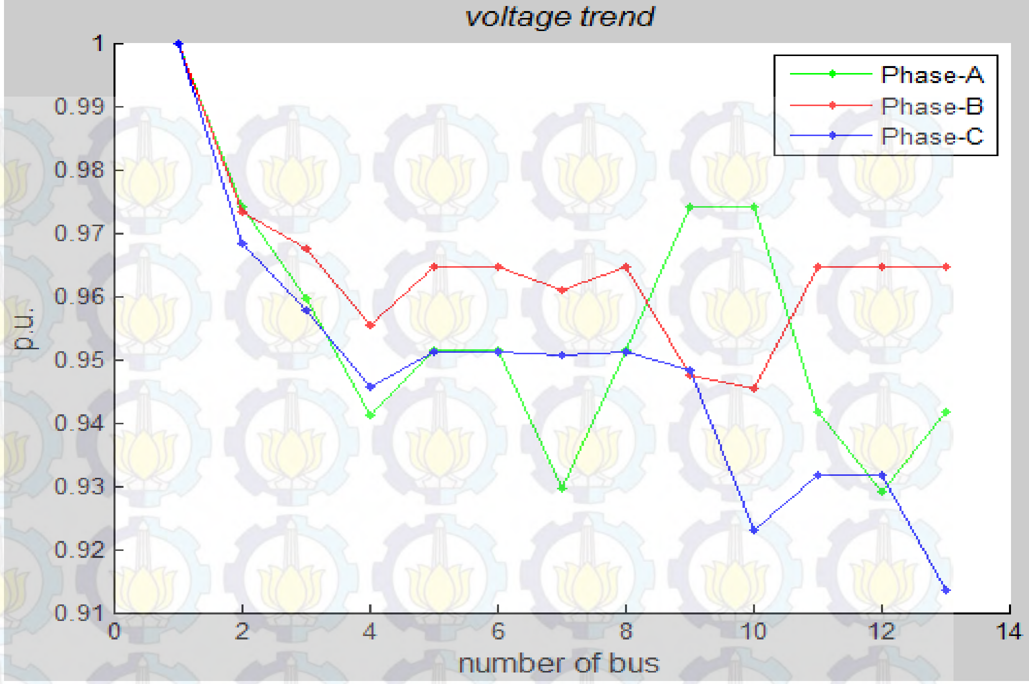


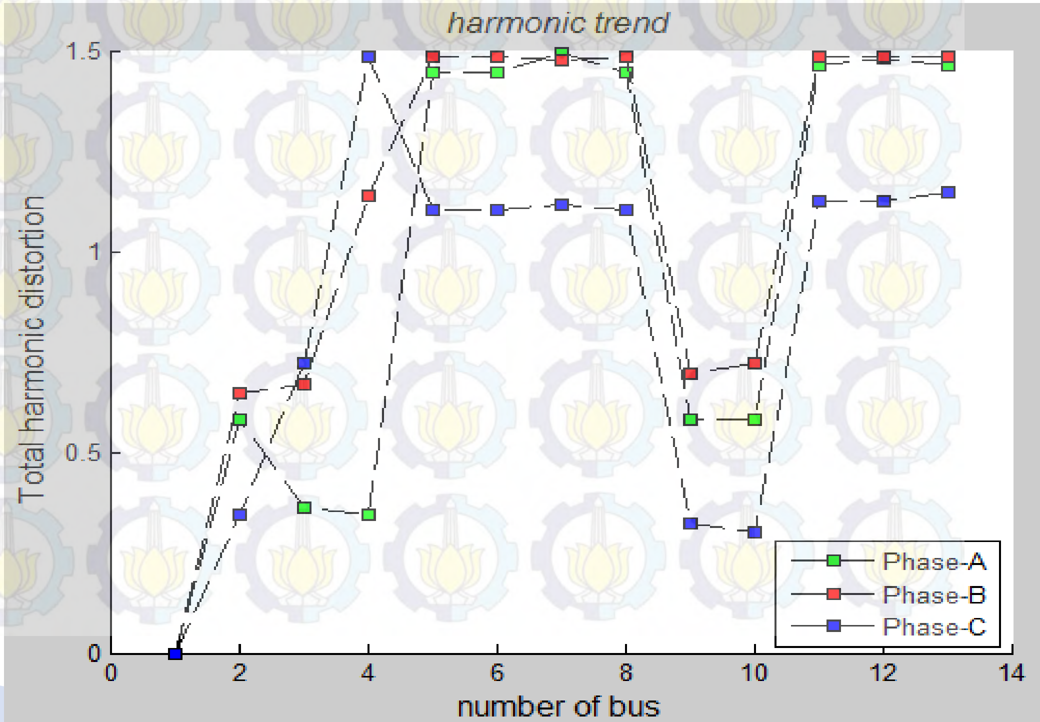
min_obj_find =
6.0087e+003 %

Best Size = 450
Best Location = 7 (3)
Max Voltage = 0.974
Min Voltage = 0.914
Max THD = 1.782
Min THD = 0.220
RealPowerLoss = 35.088

Result of Optimal Capacitor Placing and Location with LSF-Aggregated 3x150 kVAR at bus-7 phase-C

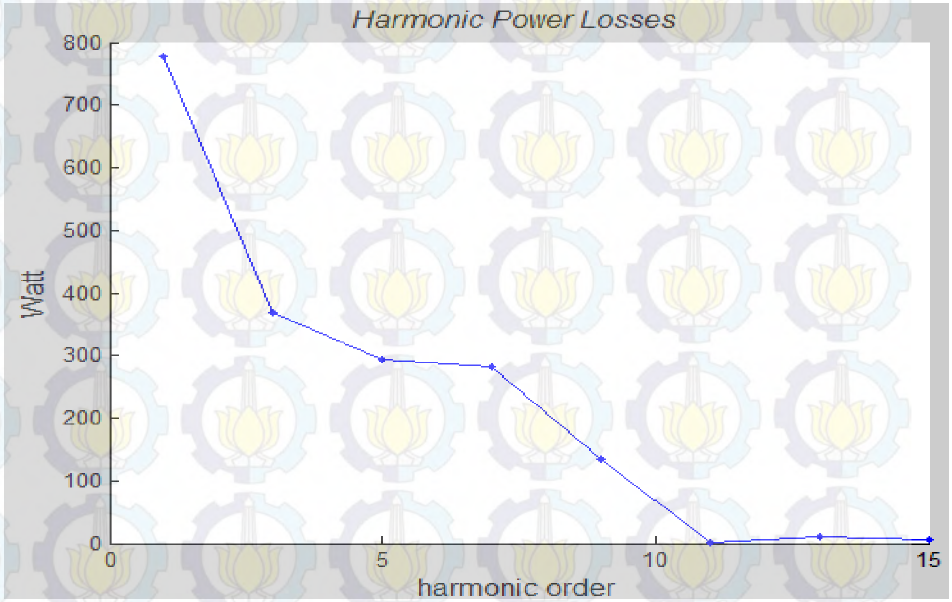
- Voltage at bus-13 phase-C is the lowest
- Bus-9 phase-A and bus-10 phase-A has the highest voltage.
- The voltage condition is within the standard.
- Recent harmonic profile are significantly within the limit.
- THD level can comply with the constraint, which is not exceeding 5 %.

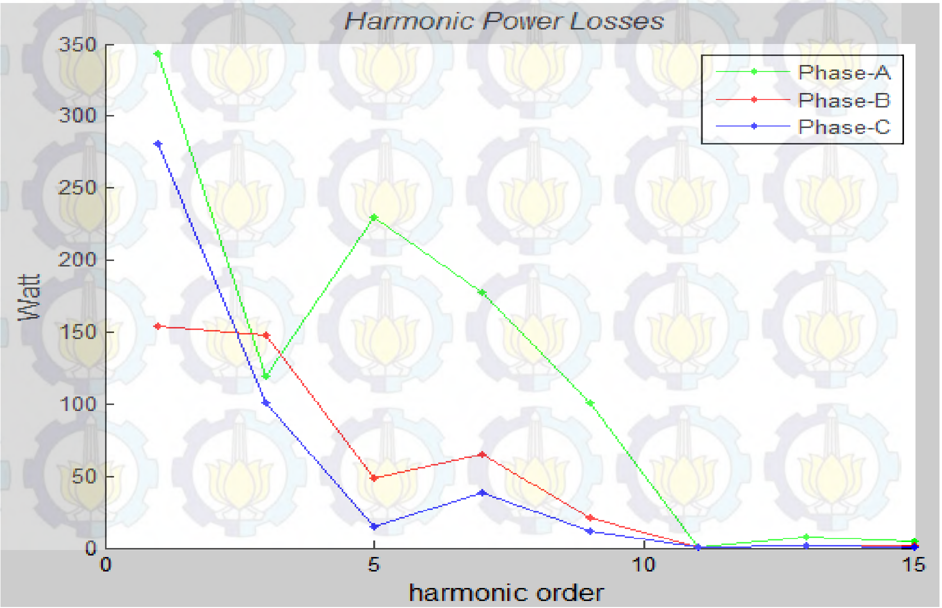




Result of Optimal Capacitor Placing and Location with LSF-Aggregated
3x150 kVAR at bus-7 phase-C

- power losses are significantly decreasing in comparison with the base case system.
- power losses in second last order of harmonic are very small
- By placing 900 kVAR at bus-8 phase-A, the harmonic penetration is reduced by half
- The harmonic penetration in phase-A are still high because it is loaded by more harmonic loads.





2. Capacitor Installation with Random Initialization

- Each bus will be identified by placing a set of capacitor to obtain the first initial condition of prospective bus.

- The total prospective buses are 10 locations
- Total searching space: 10x10x100 iteration=100 trial set
- The order of capacitor placement will be as the following picture

```
data_capacitor  = [-150*1e3 150*1e3];
data_location   = [1 36];
num_particle    = 10;  % number of random search particle
iteration_max     = 100;  % Maximum Iteration
num_variable    = 10 ;  % total candidate location
```

2. Capacitor Installation with Random Initialization

- Put the initial range of searching candidate. Each candidate will be varied among data_capacitor range.

position_particle(yy,xx)= abs((data_position(1,1)+(data_position(1,2)- data_position(1,1))*rand));

- The initial place of the capacitor will be the determined from the random value between data_location which is the total number of bus without slack bus.

position_location(yy,xx)= round(data_location(1,1)+(data_location(1,2)-data_location(1,1))*rand);

>> position_particle *** in kVAR based

55.2879	68.5001	136.1521	159.3203	35.3642	21.0342	138.6925	65.9077	77.0508	23.8421
70.5285	341.3245	69.0446	51.8890	236.4919	214.5820	69.5334	287.4869	99.9997	120.0453
25.5656	66.2997	22.8659	72.8153	13.6158	177.3984	137.3499	275.5850	69.5320	114.5795
27.4455	33.0975	43.3062	44.8373	18.3528	53.4137	110.7163	116.7248	68.2843	69.5763
50.9827	17.9850	5.8714	39.2933	74.9974	174.8063	24.7548	19.2897	250.7143	57.2615
12.8672	18.3486	6.8317	44.9025	5.3814	0.3290	36.2878	85.5971	118.1532	161.0354
210.6770	88.5317	178.6875	71.3577	164.7110	195.6544	112.2998	125.1934	41.3906	131.2099
25.5257	66.4483	52.9715	192.3479	168.6973	55.2270	36.2775	186.6170	195.9172	70.2132
66.3839	113.2313	241.6151	33.4768	160.6571	52.7339	126.6370	177.5725	109.6706	125.4770
34.4848	87.3644	144.9357	24.4538	88.7845	37.1283	109.8410	104.3029	32.4009	106.3166
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*

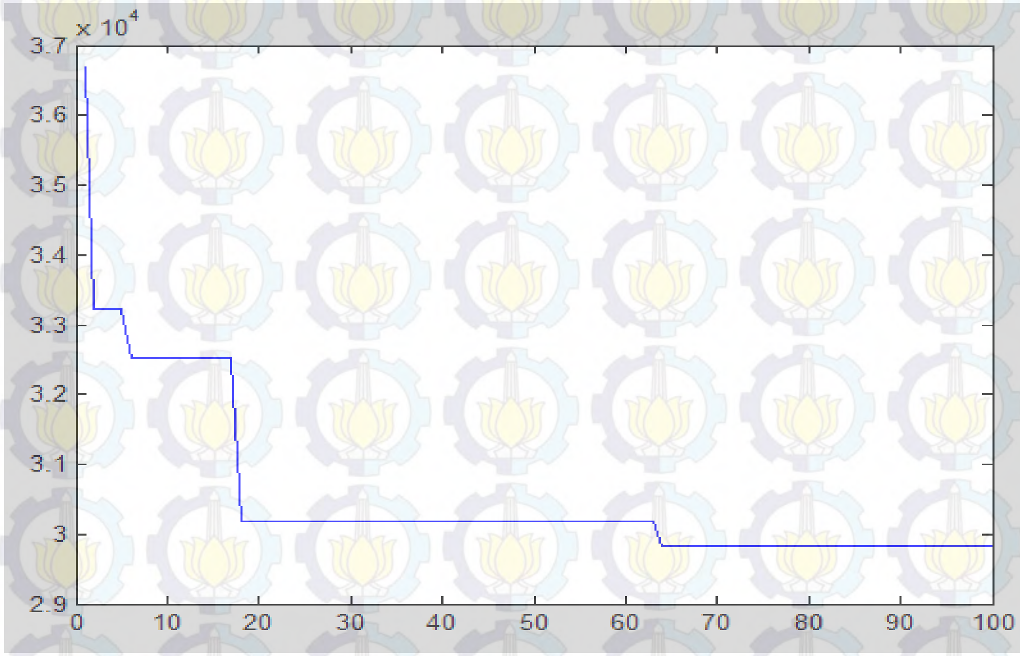
candidate set of 10 particles

position_location =

13	33	12	14	21	4	27	27	17	30
26	11	19	30	30	8	5	17	30	15
6	16	11	9	19	15	26	18	10	26
7	6	16	11	2	6	10	24	12	26
9	6	27	28	30	30	10	17	36	16
26	16	10	34	5	36	14	28	8	30
19	15	26	2	20	8	9	11	24	4
2	6	16	23	21	3	8	18	5	5
16	31	5	2	21	27	14	8	17	11
18	28	28	21	23	6	8	17	13	22
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*

candidate place

The result of DSA on placing 1 set of 10 capacitors

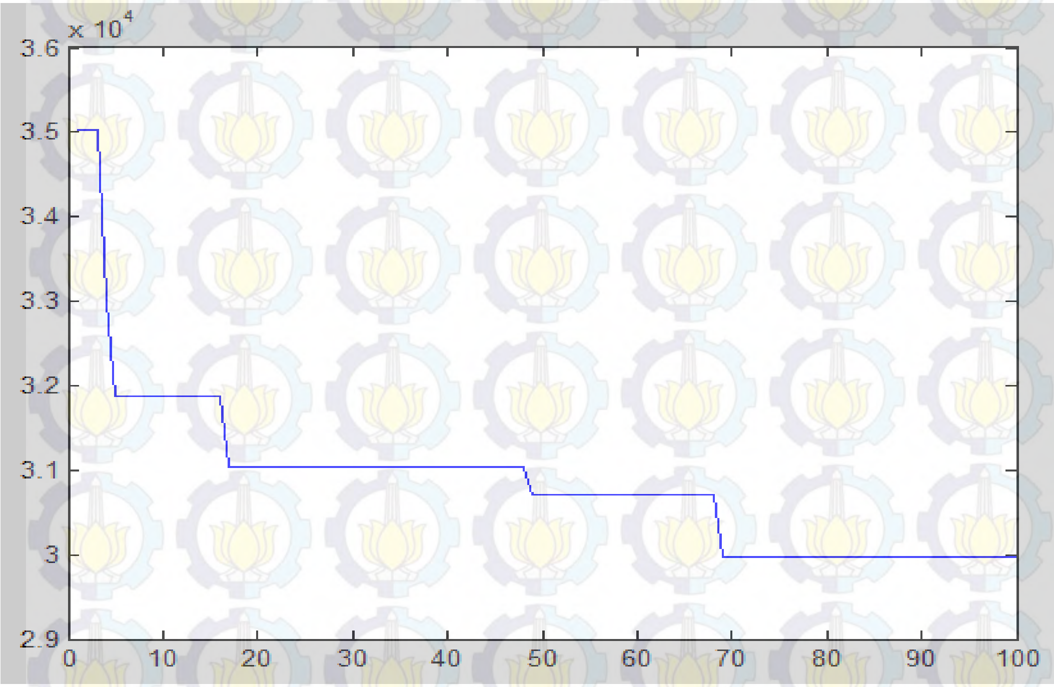


min_obj_find =
6.0087e+003 %

Best Size = 450
Best Location = 7 (3)
Max Voltage = 0.974
Min Voltage = 0.914
Max THD = 1.782
Min THD = 0.220
RealPowerLoss = 29.839

Best Capacitor	Location Index	Bus location
150	28	9-A
70	10	3-A
3	28	9-A
65	17	5-B
6	8	2-B
150	24	7-C
150	5	1-B
77	7	2-A
15	11	3-B
80	18	5-C

The result of DSA on placing 1 set of 3 capacitors



min_obj_find =
 6.0087e+003 %

Best Size = 450
Best Location = 7 (3)
Max Voltage = 0.974
Min Voltage = 0.914
Max THD = 1.782
Min THD = 0.220
RealPowerLoss = 29.980

Best Capacitor	Location Index	Bus location
240	15	5C
160	16	6A
113	21	7C

Result of Optimal Capacitor Placing and Location with PSO algorithm

(source: Eajal and El-Hawary, 2010)

	Case-1	Case-2	Case-3
Minimum Bus Voltage in p.u	0.8954	0.9555	0.9556
Maximum Bus Voltage in p.u	0.9863	0.9945	0.9947
Maximum THD in %	4.459	19.0335	1.723
Reactive Power Injection in kVAR	-	(5b) 300	(5c) 600
		(6a) 450	(6a) 450
		(6c) 600	(6b) 300
Active Power Losses in kW	192.75	164.99	165.22
Cost Function in USD/year	32,326.69	28,069	28,107
Net Savings in USD/year	-	4,257.69	4,219.69
Net Savings in %		13.17	13.05

Result of Optimal Capacitor Placing and Location with LSF-Aggregated

	Case-1	Case-2	Case-3
Minimum Bus Voltage in p.u	0.849	0.808	0.914
Maximum Bus Voltage in p.u	0.988	1.106	0.974
Maximum THD in %	2.4	16	1.78
Reactive Power Injection in kVAR		(8A) 900	(7C) 150
			(7C) 150
			(7C) 150
Active Power Losses in kW	180.083	153.146	144.995
Cost Function in USD/year	30,253.94	25,728.53	24,359.16
Net Savings in USD/year		4,690	6,009
Net Savings in %		15.5	19.86

Result of Optimal Capacitor Placing and Location with DSA

	Case-1	Case-2	Case-3
Minimum Bus Voltage in p.u	0.849	0.900	0.914
Maximum Bus Voltage in p.u	0.988	0.9954	0.974
Maximum THD in %	2.4	3.32	1.78
Reactive Power Injection in kVAR		(5C) 240	(9A) 150
		(6A) 160	(3A) 70
		(7C) 113	(9A) 3
			(5B) 65
			(2B) 6
			(7C) 150
			(1B) 150
			(2A) 77
			(3B) 15
			(5C) 80
Active Power Losses in kW	180.083	150.103	150.244
Cost Function in USD/year	30,253.94	24,166.80	25,240.99
Net Savings in USD/year		5,036.64	5.013
Net Savings in %		16.65	16.57

Conclusions

- Application of direct search algorithm in capacitor placement and sizing prediction could achieve significant result on finding the maximum net savings while maintaining the system voltage within the standard and THD limit.
- Direct search performance finds more significant net savings when it is combined with load sensitivity factor.
- Three strategies has been done to see the performance of direct search algorithm which are applying single and mutiple fixed shunt capacitor with and without load sensitivity factor.
- The result provide some understanding when the harmonics is taken into account, the system will be secure from the damage caused by hitting the thermal limit due to the less power system losses so that current that flows in the system.
- It is necessary to concern about harmonic on the system because harmonics can increase the current and when it flowing through branch impedance, the power losses of the system will be higher than normal condition.

Recommendations

- Allocation can be upgraded by using maintenance cost, installation cost, and penalty cost instead of only using aggregated installation cost of capacitor.
- DSA can be managed to work in active power flow so that the capacitor allocation strategy can solve both passive and active power system that is very suitable for the real condition.
- This capacitor allocation strategy can be implemented into the real time system which the load compositionof the distribution network will be clearly available, especially in harmonic source load. The load composition is very important which can determine the performance of the algorithm.
- Load modelling can be done in more detail such as exponential load and composite load for further understanding of the shunt capacitor application effect on distribution network.

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THANK YOU

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