International Journal of Computational and Experimental Science and ENgineering
(IJCESEN)

Vol. 11-No.3 (2025) pp. 4655-4660
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Prime Location Deployment Strategy for Phasor Measurement Units Adopting Intelligence Technique

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Article Info:

DOI: 10.22399/ijcesen.1405
Received : 05 January 2025
Accepted : 26 March 2025

Keywords

Phasor Measurement Unit,
Performance Index,
Particle Swarm Optimization.

Abstract:

Optimized handling of existing assets in electrical systems are mandatory with rapidly developing complex smart networks. Power systems superior operation targeted through successful deployment of PMU by streaming live data quickly and securely enforcing crucial preventive measurement. In spite supremacy of PMU over traditional measurement regarding various aspects, it is nonviable to place PMU over entire system at each bus because of relatively expensive cost of PMU. Therefore, PMUs are imperative to be placed optimally over system in prime location. An intelligent PSO technique tested on IEEE Five Bus and Fourteen Bus System. The adopted technique achieves minimal number of PMUs and prime location deployment of PMUs for IEEE Five Bus and Fourteen Bus System.

1. Introduction

Prediction of system status needs monitoring, controlling and protection in real time which pivot on synchronized technology [1]. Synchronized measurement of existing network status achieved quickly by installation of PMU as SCADA efficacy is relatively small**.** Ample system issues are solved through information provided by Phasor Measurement Unit [2]. State estimation evaluation signifies that enhancement in performance can be achieved by combining traditional measurements with PMU assessments under base and contingency situations. It is troublesome to place PMU in each node of large interconnected network. Implementation of PMU grows slowly despite of enormous applications in real time. Successful deployment of Phasor Measurement Unit requires careful design due to heavy installation and network cost. Installation of PMU in every node accumulate repeated data increasing traffic of monitoring system in control centre. Selecting minimum number of PMUs with system observability are major motive of optimal placement solution.

Several optimization strategies adopted to determine prime PMU placement are Integer Linear Programming, Simulated annealing, Exhaustive search, Genetic Algorithm, Differential Evolution, Tabu Search and Binary PSO [3,4]. Meta-heuristic algorithms uplift itself compared to Integer linear programming method as optimal placement of PMU does not have unique solution. Present optimal placement solution might be improved with meta-heuristic algorithms since randomization is incorporated in framing algorithm. Binary PSO method adopts intelligence of particles, fast convergence and ease of implementation to obtain adequate solution. An intelligent PSO algorithm belongs to class of meta-heuristics. PSO is successfully applied to various fields of science and engineering. PSO is a swarm intelligence method created by some unintelligent agents like representatives to reach an upper level of intelligence which is absolutely unreachable for any of representatives in swarm. Population of representatives locally interact with themselves and their environment to create global environment. Each representative propulsion is impacted by its local prime known location that influence towards prime known location in search space. When an admissible control parameter of any representative surpasses searching space its value will be reset. Simplicity and adorability of PSO led to popularity and extensive application in solving optimization problems. Genetic Algorithm resolves issues by developing candidate with natural choice [5,6].

2. Methodology

Fitness value of each representative is determined by PSO intelligent iterative technique. Initiation of PSO technique is carried out by mass of arbitrarily representatives. Each representative search for prime value by updating iteration. Reducing number of PMUs in IEEE Five and Fourteen bus system being main motive of fitness or cost function under contingency. Basic rule of PMU allocation is that when device is mounted on a node, PMU must be capable of measuring voltage vector at particular node and adjacent nodes by connecting corresponding transmission lines [7].

Objective function,

Z = max (C)………………. (1)

Where C relies on performance index of Real Power, Voltage and Percentage loading estimated for single line contingency respectively [8,9]. This method considers maximum value of indices for ranking buses. Each representative or particle of swarm follow certain rules to achieve prime spot in search space being best former position for every representative is called particle best. Superior position among all the representative best position obtained so far is known as global best.

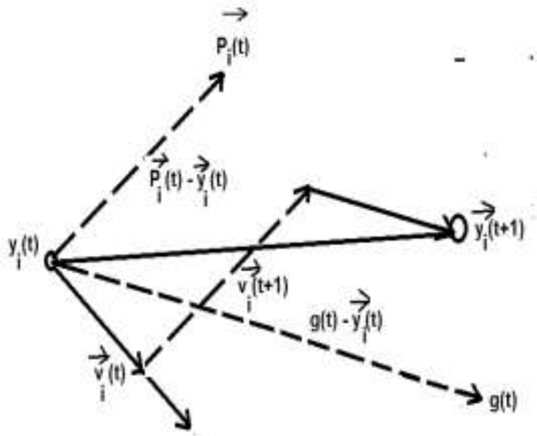

Figure 1: *Geometrical model of PSO*

The rate of propel for each representative is called particle velocity. In every iteration representative position and propel rate is updated [10-15]. Figure 1 explains Geometrical model of PSO. Collaboration among representatives by communicating and educating to follow rules in swarm boosts intelligence height. Apart from spot and propulsion every representative has remembrance of its best spot known as Personal best. Swarm experience of all representatives termed as Global best without any index. New spot of representative depends on three vectors first one parallel to v_i (t), second vector connecting $y_i\ (t)$ to $p_i\ (t)$ and third one $y_i\ (t)$ to g(t). New spot of representative is derived from vector sum of all three components and new representative propulsion.

Equation for updating the location of representative or particle

$y_i(t+1)$ = y_i(t) + $v_i(t+1)$ …………. (2)

Equation for updating the position and propulsion of representative or particle

$v_i\ (t+1)\ =\ $ w $v_i\ (t)\ +\ c_1$ [$p_i\ (t)$ - y_i (t)] + c_2[g (t) - y_i (t)] …………………. (3)

$v_{ij}\ (t+1)$ = w $v_{ij}\ (t)$ + $r_1\ c_1$ [$p_{ij}\ (t)$ - y_{ij} (t)] + r_2 c_2[$g_j\ (t)$ - y_{ij} (t)] ………… … (4)

$y_{ij}\ (t+1)$ = y_{ij}(t)+ $v_{ij}\ (t+1)$ …….. (5)

Equation (4) and (5) indicates rules followed by each representative in swarm.

c_1 and c_2 → Acceleration coefficients 1.5 and 2.0 respectively.
r_1 and r_2 → Randomly chosen between o to 1
$r_1 c_1[p_{ij}\ (t)$ - y_{ij} (t)] and $r_2\ c_2[g_j\ (t)$ - y_{ij} (t)] → Cognitive and Social component.
v_i (t) → Propulsion direction of representative or particle.
$p_i\ (t)$ → Personal best for every representative or particle.
$g_i\ (t)$ → Global or common best for every representative or particle.
w → Inertia Coefficients = 1
w_{damp} → Inertia weight damping ratio = 0.99
$y_i\ (t)$ → Current spot of representative.
$y_i\ (t+1)$ → New spot of representative

If c_1 has higher number, propulsion of representative will be heading towards personal best which restricts impact of c_2. When w ≥ 1, representative propulsion rate is accelerated till maximum velocity reached. When w ≤ 1, representative deaccelerate and velocities will be minimum. All representatives will propel through search space with their positions relocated on the basis of self-experiences or subordinate experiences. Stability Principle of swarm depends

on propulsion of representative which occurs only when swarm's prime spot is altered. PSO begins by randomly initialising particles in swarm and uniformly distributed within defined search space. Each representative is associated with velocity and position vector. Swarm size, Number of iterations, propulsion rate, Inertia weight, acceleration constants, number of decision variables and variable limits are various parameters to be selected in PSO technique while used in optimization problem. PSO technique is adopted in IEEE 5 and 14 bus system to obtain best solution for optimum employment of PMU by using MATLAB Program. Due prominence given for reducing number of PMUs as cost plays major role. Hybrid heuristic GA based PSO approach
enhances capability of PMU in exponentially growing real time system [16-22].

3. Result and Discussion

In PSO technique every representative has memory of best experience from beginning of algorithm to current state. Every representative has own cost value. Position, velocity, best and cost are the four key components in PSO. Every representative creates random spot in search space. Performance Indices estimated for one line contingency considering cumulative effect of Real power, Voltage and Percentage loading. As complexity of system rises, screening critical line outages will be challenging task for an operator. Deficiency of situational awareness handling capability of operator will lead to black out. Rapid Preventive measurement is feasible with adequate planning of PMU deployment in proper prime selected buses. Performances indices are primary factors considered to allocate PMUs adopting PSO which supplies reliable data for an operator in control centre.

Table 1 represents Real Power performance index calculated considering N-1 Contingency using NR Load flow investigation for IEEE Five bus system. When Line 1-2 opened, Real Power performance index of Line 1-3 is highest and Line 2-4 has minimal value. Higher value of Real Power performance index imperil system more during outage compared to Line 2-4. When Line 4-5 opened, Real Power performance index of Line 1-2 is highest and Line 3-4 has minimal value. Table 2 represents Percentage loading performance index with N-1 contingency condition for IEEE Five Bus system. When Line 2-3 is opened Percentage loading performance index of Line 1-2 is larger. Performance indices calculated for IEEE Fourteen Bus system with Real Power, Voltage and Percentage loading by opening single line. PSO technique is adopted to calculate cumulative impact of Real Power performance index, Voltage performance
index and Percentage loading performance index. The maximum value of cumulative impact of Real Power, Voltage and Percentage loading is basis of cost function. Performance index is the deciding factor in PSO for prime allocation of PMU. Figure 2 to 9 depicts impact of Real Power performance index evaluated with Line 2-5, 12-13, 4-5, 13-14, 10-11, 9-14, 6-12 and 5-6 open respectively in IEEE Fourteen Bus system. Figure 10 and 11 signifies Percentage loading performance index evaluated with Line 2-5 and 4-5 open in IEEE Fourteen Bus system. Buses 1, 2 and 12 are optimum solution in search space for prime location of PMU in IEEE Fourteen Bus system. Performance index of Bus 1 indicates frequency of occurrence as 35 times in search space and largest compared with remaining buses having 50 as best cost value. Similarly, Bus 2 indicates frequency of occurrence in search space is 34 times and bus 12 frequency of occurrence is 18 times. As frequency of occurrence increases the cost function search has reached optimum value. Table 3 specify quantity of PMUs necessary for IEEE Five and Fourteen Bus system. Number of PMUs estimated for IEEE Five and Fourteen Bus systems are two and three respectively. The response time of PSO algorithm is 62.38 s and 139 s in IEEE Five and Fourteen Bus system respectively. Maximum cost function occurrence determines maximum performance indices for IEEE Five and Fourteen Bus system. Buses 1 and 2 are optimum solution in search space for prime location of PMU in IEEE Five Bus system. Performance index indicates frequency of occurrence in search space which is largest compared to other buses with best cost value. Table 4 represents performance indices for IEEE Fourteen Bus system. The limited quantity of PMU is the need of current system and achieved by adopting PSO method in IEEE Five Bus and Fourteen Bus system. Frequency of execution of algorithm is decided on the basis of number of iterations selected. As number of iterations rises time consumed by PSO to complete execution increase even when it converges. If iterations selected are too low, then algorithm may end prior to convergence. Selection of iterations must be chosen intelligently to obtain optimum solution for cost function from selected algorithm.

Figure 12 represents graph with iteration on x axis and best cost on y axis. The best cost function remains same for all iterations from 1 to 10. Best cost function value remains 50 as shown in graph. Maximum cost function determines maximum performance indices. The buses with maximum performance indices are ultimate spot for placement of PMU. Despite extensive demands of PMUs, its installation rate is not rapid due to price factor.

Reduction in computation time increases efficacy of system and solution can be derived in faster mode among largely increasing complex systems. Minimum number of PMUs plays prominent role in budget allotment and reduction in computation time has prime significance in rapidly developing smart grid.

4. Conclusion

Trustworthiness, vigorousness and low budget components play crucial role in exponentially increasing volume of electrical grid. The hurdle for

Table 1*: Performance Index for Real Power Flow in IEEE Five Bus system*

SL. No	Lines	Line 1-2 open	Line 1-3 open	Line 2-3 open	Line 2-4 open	Line 2-5 open	Line 3-4 open	Line 4-5 open
1	Line 1-2	0	0.08028936	0.03089256	0.03150383	0.03084165	0.04365939	0.03828118
2	Line 2-5	0.00763702	0.00763702	0.01834464	0.01985155	0	1.88E-02	0.0188323
3	Line 2-4	8.69E-05	8.69E-05	7.94E-03	0	0.01492097	8.67E-03	3.29E-03
4	Line 2-3	0.00129905	0.00984806	0	0.00743829	1.08E-02	0.00085534	0.00269917
5	Line 4-5	0.00266685	0.00266685	3.46E-06	1.45E-05	0.02036717	7.70E-09	0
6	Line 1-3	0.08703983	0	0.01213221	0.01182613	0.01465834	5.71E-03	0.0078842
7	Line 3-4	0.02567904	0.02567904	3.53E-05	0.00864134	1.53E-02	0	1.38E-03

Table 2*: Performance Index for Percentage Loading in IEEE Five Bus system*

SL. No	Lines	Line 1-2 open	Line 1-3 open	Line 2-3 open	Line 2-4 open	Line 2-5 open	Line 3-4 open	Line 4-5 open
1	Line 1-2	0	124.5	76.7	77.4	76.4	91.3	85.3
2	Line 2-5	45	61.2	58.6	61.1	0	59.1	59.8
3	Line 2-4	10.1	42	38	0	53.9	39.3	25
4	Line 2-3	19.7	42.5	0	36.5	45.2	15.2	22.7
5	Line 4-5	25.3	3.2	3.8	4.2	66.6	3.7	0
6	Line 1-3	142.5	0	46.8	46.1	52.4	31.6	37.2
7	Line 3-4	75.4	7.6	9.5	38.1	52.2	0	15.4

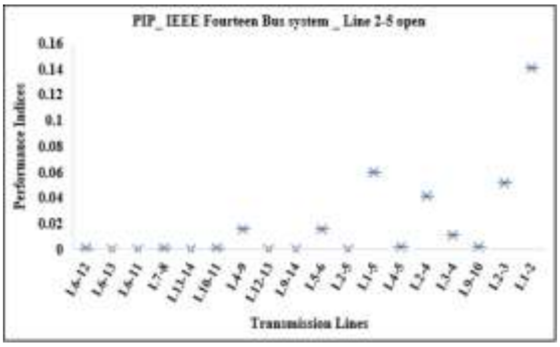

Figure 2: *PIP_ Performance Indices for IEEE Fourteen Bus system with Line 2-5 open*

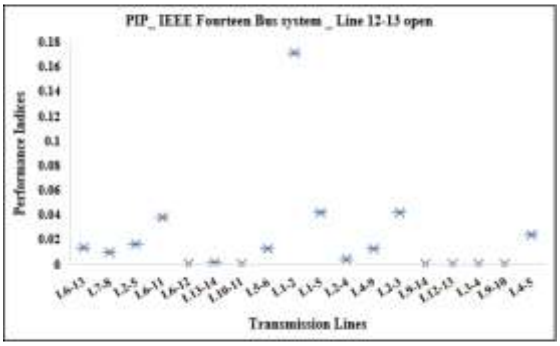

Figure 3: *PIP _ Performance Indices for IEEE Fourteen Bus system with Line 12-13 open*

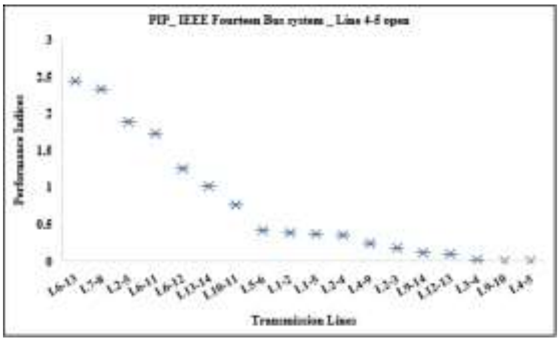

Figure 4: *PIP _Performance Indices for IEEE Fourteen Bus system with Line 4-5 open*

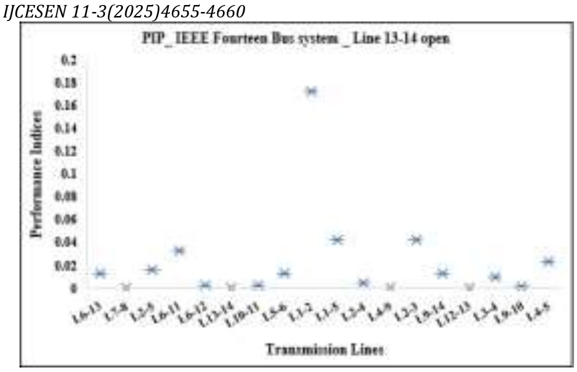

Figure 5: *PIP_ Performance Indices for IEEE Fourteen Bus system with Line 13-14 open*

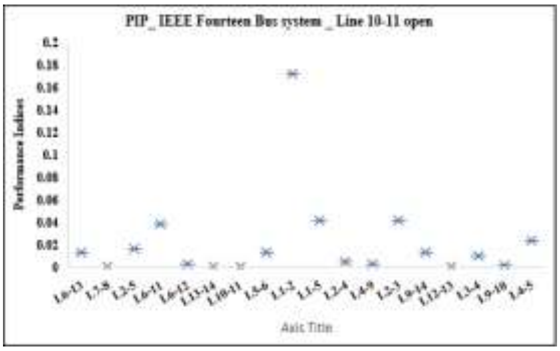

Figure 6: *PIP _Performance Indices for IEEE Fourteen Bus system with Line 10-11 open*

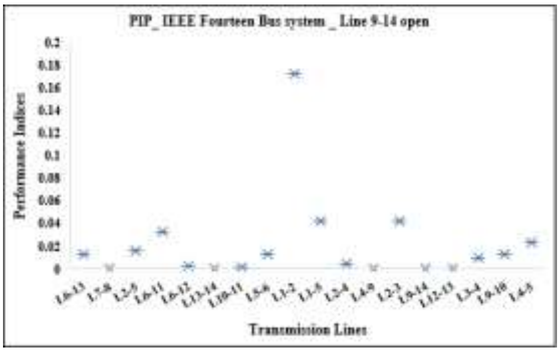

Figure 7: *PIP_ Performance Indices for IEEE Fourteen Bus system with Line 9-14 open*

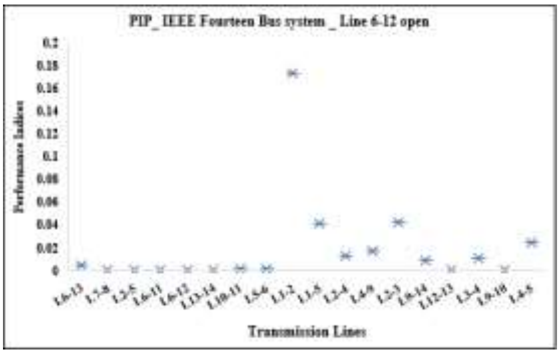

Figure 8: *PIP _Performance Indices for IEEE Fourteen Bus system with Line 6-12 open*

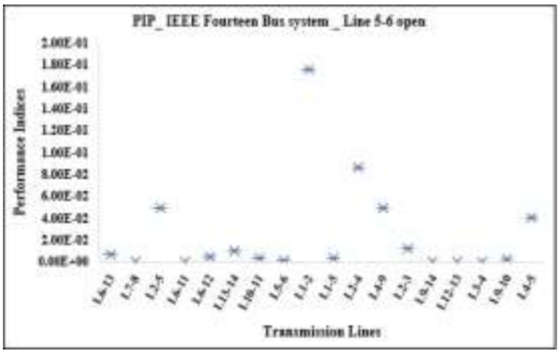

Figure 9: *PIP_ Performance Indices for IEEE Fourteen Bus system with Line 5-6 open*

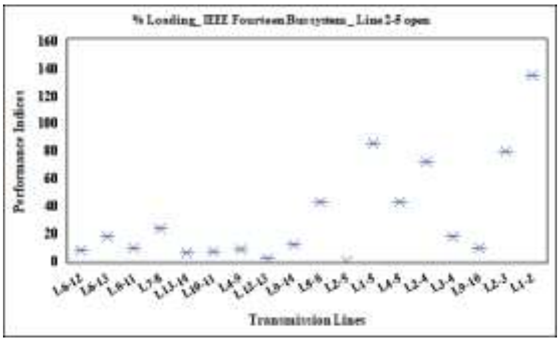

Figure 10: *% Loading _Performance Indices for IEEE Fourteen Bus system with Line 2-5 open*

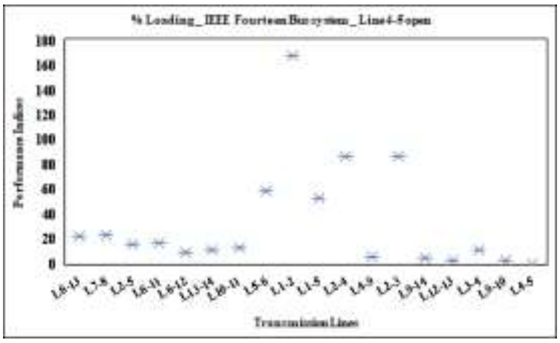

Figure 11: *% Loading _Performance Indices for IEEE Fourteen Bus system with Line 4-5 open*

Table 3: *PMU Deployment for IEEE Five and Fourteen Bus system with PSO Technique.*

Case Study System	Number of PMUs	Prime PMU Location buses	Computation Time (s)
Five Bus	2	1,2	62.38
Fourteen Bus	3	1, 2, 12	139

Table 4*: Performance Indices of IEEE Fourteen Bus system with PSO Technique.*

Bus	Performance Indices
1	35
2	34
12	18

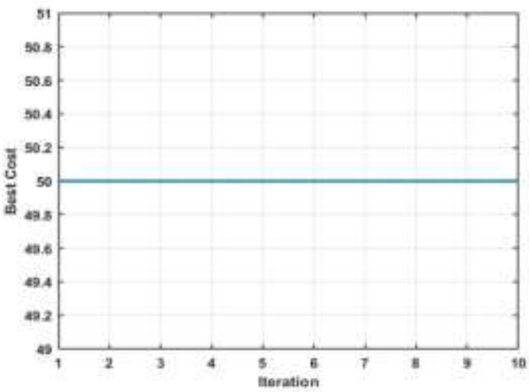

Figure 12: *Best Cost function for IEEE Fourteen Bus system with PSO Technique.*

defensive operation of Power system is precise assessment of pool complex data handling in short interval by operator in control centre. PMU acts as boon in resolving such problem. The conflict nature of economy and security is the extended challenge to be resolved primarily in interconnected systems.
PMU is an advanced promising smart technology adopted in modern Power system for enormous security operations. But price is also deciding factor that restricts PMU installations at every bus. Clever and prime placement allocation with minimum number of PMUs is achieved intelligently by PSO technique. The Intelligence technique is tested on IEEE Five Bus and Fourteen Bus systems. Reduction in feasible number of PMUs installation refers to improvement in economy of system. Determining status of system precisely by measuring network parameters sharply demands development of a technique with reduced computation time. Overall computation time needed to determine optimum solution by Particle Swam Optimisation method is more. GA technique overcomes algorithm response time issue as computation time required is superior compared to PSO method.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.

Data availability statement: The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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