

# Chaotic Mutation Immune Evolutionary Programming for Voltage Security with the Presence of DGPV

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## Abstract

Due to environmental concern and certain constraint on building a new power plant, renewable energy particularly distributed generation photovoltaic (DGPV) has becomes one of the promising sources to cater the increasing energy demand of the power system. Furthermore, with appropriate location and sizing, the integration of DGPV to the grid will enhance the voltage stability and reduce the system losses. Hence, this paper proposed a new algorithm for DGPV optimal location and sizing of a transmission system based on minimization of Fast Voltage Stability Index (FVSI) with considering the system constraints. Chaotic Mutation Immune Evolutionary Programming (CMIEP) is developed by integrating the piecewise linear chaotic map (PWLCM) in the mutation process in order to increase the convergence rate of the algorithm. The simulation was applied on the IEEE 30 bus system with a variation of loads on Bus 30. The simulation results are also compared with Evolutionary Programming (EP) and Chaotic Evolutionary Programming (CEP) and it is found that CMIEP performed better in most of the cases.

**Keywords:** DGPV system, Fast Voltage Stability Index, Chaotic Mutation

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## 1. Introduction

In the future, the integration of DGPV to the transmission system is expected to increase in electric power system infrastructure planning and market operations due to continuous load growth and limitation of generation capacity construction faced by the utility companies. The purpose of DGPV is to harvest and supply the energy from the solar in order to address the growing demand for electrical power. Integrating DGPV unit into the power system can contribute to several benefits to the utility companies such as the reduction of system losses and network operating costs [1]. To achieve these benefits, an appropriate size and place must be selected to install the DGPV units. In addition, power losses can be reduced up to 40%-70% with proper location of DGPV. Furthermore, the number and the capacity of the DGPV unit also contribute to voltage stability improvement [2]. Hence, systematic studies and planning are required to locate and operate the DGPV at the transmission level in order to improve voltage profile, reduce losses and to enhance the stability. Previously, different techniques have been developed to determine the optimal location and size of the DG. These techniques are either based on analytical tools or on optimization programming techniques. Analytical approaches have been suggested by several authors. In [3-4], the authors presented an analytical approach namely sensitivity analysis technique to determine the optimal allocation for the combination DG and capacitor with an objective of loss minimization for distribution system. In [5], the author used loss allocation method by Shapley Value (SV) concept to determine the optimal size and location of DG based on branch losses. The method is simple but time consuming for searching both the best location and optimum size. Voltage stability is one of the major issues in monitoring the power system stability. Several studies have applied DG in the system in order to enhance voltage stability by using voltage stability indices [6]. In [7], a new proposed voltage stability index in radial distribution network has been derived to obtain optimal location and sizing of DG for loss minimization and voltage stability enhancement with respect to load variation. Revamp Voltage Stability Index (RVSI) is developed in [8] for optimal allocation of DG and Static VAR Compensator (SVC) in 14-IEEE bus system. Based on

RVSI, the weak area was identified for DG or SVC allocation. The author concluded that DG has more impact on loss reduction and voltage stability improvement compared to SVC.

Recently, metaheuristics optimization techniques are being successfully applied to optimization problems in power systems [9]. Among those techniques, evolutionary programming (EP) is considerable a popular technique because of its simplicity, easy implementation and reliable convergence. EP has the fast converging pattern and good global searching at the beginning of the simulation. However, EP faces the local minima problem at the end of the program [10]. In order to overcome the local optima and obtain better convergence, chaos is introduced. Chaos is a characteristic that describes the complex behavior of a nonlinear deterministic system [11]. Based on these features, much of chaos as a science is connected with the notion of 'sensitive dependence on initial conditions' [12].

Chaos theory has been adopted successfully in many engineering applications such as in mechanical and electrical engineering [13]. Moreover, chaos theory and the generation of chaotic sequences is widely used to replace the random sequences which has led to very interesting results in many applications, such as optimization of power flow problems [14], control systems [15], neural networks [16], robotics [17] and others. Optimization algorithms based on the chaos theory are stochastic search methodologies that have its own advantages over the existing evolutionary computation and swarm intelligence methods. Due to the non-repetition of chaos, it can carry out overall searches at higher speeds than stochastic ergodic searches that depend on probabilities. In this case, the utilization of chaotic optimization approaches can more easily escape from local minima than can other stochastic optimization and direct search algorithms, such as multi-directional search, simulated annealing, pure adaptive search, evolutionary algorithms, swarm intelligence, and others [18–20]. A chaotic sequence based on a chaotic map that acted as a randomizer was integrated with PSO to replace the traditional uniform random function for solving the economic dispatch problem [21–22]. The proposed combined method outperforms other modern metaheuristic optimization techniques the two constrained economic dispatch case study. In [23], Adaptive chaos clonal evolutionary programming (ACCEP) is employed to deal with the short-term active power scheduling of a stand-alone system to minimize the CO<sub>2</sub> emissions with certain constraints. The study showed that with the integration of chaos the simulation converged within a reasonable time. In [24], chaotic particle swarm optimization (CPSO) was developed to detect the maximum loadability limit in 14 IEEE bus system. Chaos is incorporated to add diversity to the particles. The proposed CPSO technique is able to overcome the stagnation of the program near and provides reliable convergence. Additionally, CPSO technique can achieve higher maximum loadability factors under different voltage limits.

This paper presents Chaotic Mutation Immune Evolutionary Programming (CMIEP) for voltage security with the presence of DGPV. In this paper, CMIEP has been applied for optimal allocation of DGPV for enhancement of voltage stability in the power system. A comparison of techniques is presented between CMIEP, Chaotic Evolutionary Programming (CEP) and Evolutionary Programming (EP) with minimization of Fast Voltage Stability Index (FVSI). Results obtained from the study revealed that CMIEP outperformed EP and CEP in most of the cases in term of FVSI reduction and overall power system losses.

## 2. Notation

The notation used throughout the paper is stated:

*Indexes:*

$Z$	line impedance
$Q_j$	receiving bus
$V_i$	voltage at the sending bus
$nr$	number of transmission line
$k$	number of DGPV
$P_{DG_i}$	generated power from DGPV
$P_{Generation}$	generated power from the power station
$N$	number of bus in the system
$P_L$	total active power load
$P_{Loss}$	total active power loss

$P_{DG\min}$	lower limit of DGPV size
$P_{DG\max}$	upper limit of DGPV size
$P_i$	size of a DPV
$V_{\min}$	lower limit of voltage limit
$V_{\max}$	upper limit of voltage limit
$V_i$	voltage magnitude at bus $i$
$x_n$	initial state
$p$	control parameter

### 3. Research Method

#### 3.1. Minimization of FVSI

FVSI has been widely used as a tool for voltage stability assessor. FVSI is developed based on the 2-bus power system, considering power flow via a transmission line [25]. The value of FVSI range from 0 to 1. The increment in the value of FVSI indicates that the poor performance of voltage stability in the system. The system is unstable and may face voltage collapsed when the FVSI value is greater than 0.95. The mathematical equation of FVSI is written as:

$$FVSI_j = \frac{4Z^2 Q_j}{V_i^2 X} \quad (1)$$

Hence, the objective function,  $f$  is to minimize the FVSI and control the voltage level within the acceptable limit.

$$f = \text{Min}(FVSI) \text{ for } \forall i \in nr \quad (2)$$

This study only consider the FVSI variation when the DGPV is installed in static mode. The dynamic nature such as the variation of solar irradiance and time domain analysis is not considered for this study.

#### 3.2. Constraints

The transmission network contains generator buses known as PV bus (power station), load buses known as PQ bus, (customers) and swing bus. Each PQ bus in the power system is connected to PV bus. The power is supplied to various areas via the transmission lines. The most common location of grid connected DGPV are at the load buses due to a shorter distance for power transfer to the customer and can contribute to minimal power losses. Several constraints should be taken into account while trying to optimize both location and size of the DGPV. The constraints are as follows:

##### 3.2.1. Active Power Balance

Referring to principle equilibrium, the power losses and load should be equal to the power generated from the DGPV unit and the power station.

$$\sum_{i \in k} P_{DG_i} + P_{\text{Generation}} = \sum_{i \in N} P_L + P_{\text{Loss}} \quad (3)$$

##### 3.2.2. Size of DGPV

The solar irradiance data for 24 hours has been modeled in PSS<sup>®</sup>E by Adrian W. H. Sie et al in [26]. From the model, the result showed that the DGPV output varies based on the solar irradiance. Therefore, the inequality constraint for the sizing is given as below.

$$P_{\min} \leq P_i \leq P_{\max} \quad \forall i \in k \quad (4)$$

### 3.2.3. Bus Voltage

The bus voltage magnitudes are bounded between two acceptable operation limit. In this research, the power factor of the DGPV is assumed as unity power factor. The inequality constraint on voltage of each bus is expressed as shown in Equation (5).

$$v_{\min} \leq v_i \leq v_{\max} \quad \forall i \in N \quad (5)$$

### 3.3. Power System with the Presence of DGPV

Recently, the integration of renewable energy (RE) into the grid system has escalated dramatically around the world. Among these alternative sources of renewable energy, the solar photovoltaic (PV) cell has proven to be the best renewable energy source with least negative impacts on the environment due to its flexibility in term of location and availability compared to other RE sources [27]. DGPV can be in term of the solar farm is connected to the transmission line and act as a power generation unit. DGPV has many advantages over centralized power generation including reduction in power losses, improvement in voltage profile and system stability, reduction in pollutant emission and relieving transmission and distribution system congestion [28-29]. However, the performance of DGPV in term of reduction of power losses in the system dependent upon the solar irradiance penetration level. Therefore, the optimum location and sizing of DGPV may reduce the power losses and improve the voltage profile within the allowable limit [30].

### 3.4. Chaotic Mutation Immune Evolutionary Programming (CMIEP)

In CMIEP algorithm, the concept of optimization is based on evolutionary programming (EP) and artificial immune system (AIS). Additionally, chaotic sequence was applied as an alternative to provide diversity in mutation of the approaches. The piecewise linear chaotic equation is adopted for the mutation.

#### 3.4.1. Evolutionary Programming (EP)

Evolutionary Programming (EP) is a stochastic optimization technique based on the natural generation and was invented by D. Fogel for prediction of finite state machine [31]. The process involves random number generation at the initialization, followed by statistical evaluation, fitness calculation, mutation and finally new generation created as the result of the selection. Traditionally, in most of the EP algorithm, mutation process was based on the Gaussian general equation for random modification of the individuals with a small probability.

#### 3.4.2. Chaotic Mutation Based on Piecewise Linear Chaotic Map (PWLCM)

PWLCM has gained increasing attention in chaos research recently due to its simplicity in representation, efficiency in implementation, as well as good dynamical behavior. It has been known that PWLCMs are ergodic and have uniform invariant density function on their definition intervals [32]. The PWLCM with four segments [18], [33] can be denoted in equation (6) as given below. The PWLCM behaves chaotically in (0,1) when  $p$  is between 0 and 5. In this work,  $p=0.4$  is heuristically chosen for the mutation process.

$$x_{n+1} = F(x_n, p) = \begin{cases} \frac{x_n}{p}, & 0 \leq x_n < p \\ \frac{(x_n - p)}{(0.5 - p)}, & p \leq x_n < 0.5 \\ \frac{(1 - p - x_n)}{0.5 - p}, & 0.5 < x_n < (1 - p) \\ \frac{1 - x_n}{p}, & (1 - p) < x_n < 1 \end{cases} \quad (6)$$

Where

$$x_n \in [0, 1], \text{ initial state}$$

$$p \in [0, 0.5], \text{ control parameter}$$

### 3.4.3. Flowchart of CMIEP

For a transmission network, load flow analysis is carried out and FVSI value is computed for each line using Equation (1). For  $i$ - $j$  line having the highest value of FVSI, the DG will be placed at  $j$ th bus. The CMIEP algorithm is used for finding the optimum size of DGPV at optimum location based on a minimum total power loss, with constraints given in equation (3–5). In this study, the 30 Bus IEEE RTS is used as the test system. The complete flow chart for DGPV allocation and sizing is represented in Figure 1.

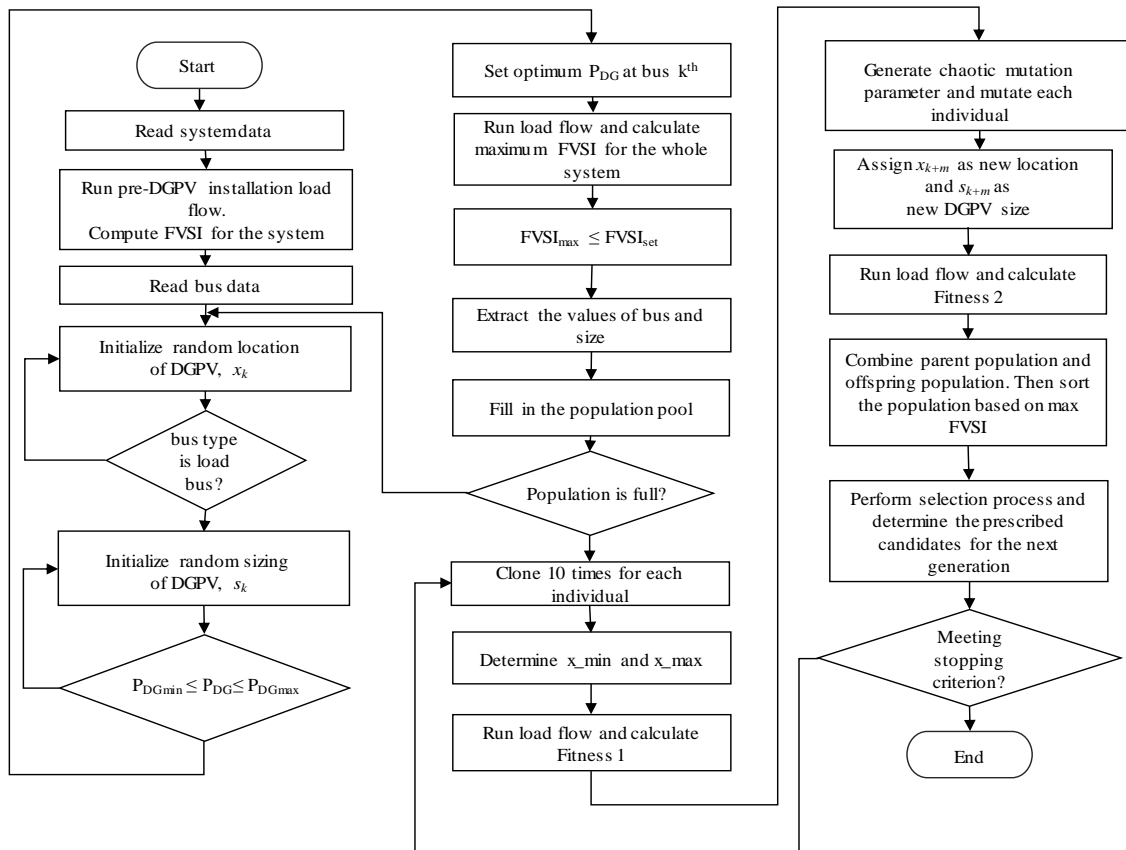


Figure 1. Flowchart of CIMEP algorithm for DGPV allocation and sizing

## 4. Results and Analysis

The application of the proposed technique (CMIEP) to power system has been examined in three different cases as single, two and three DGPV installations. The cases were tested on IEEE 30-Bus radial transmission system (RTS). The reactive power at Bus 30 was varied at 8, 16, 24 and 32 MVAR for all the cases. The FVSI value without the DGPV unit is taken as the base case. For each case, the reduction of FVSI optimized using CMIEP is compared to those optimized using EP and CEP.

Figure 2 shows the results for single DGPV installation optimized using EP, CEP and CMIEP with a variation of reactive power loading at Bus 30. The results are also compared with the system without DGPV installation. When Bus 30 was reactively loaded with 8 MVAR, the highest FVSI reduction, 17.73% is experienced as compared to other loading condition. At 32 MVAR reactive power loading, CMIEP underwent FVSI reduction of 10.60% as compared to EP and CEP worth 9.30% and 7.53% respectively. Figure 3 shows the results for two DGPV installations with a variation in reactive power. The CMIEP, EP and CEP showed the highest FVSI reduction with 23.4%, 21.66% and 21.14% respectively when 8 MVAR was reactively loaded at Bus 30. CMIEP also shows the best performance at 32 MVAR loading with reduction of 11.14%. Figure 4 shows the comparison of FVSI reduction for three DGPV installations. The

same observation can be seen in this figure. The CMIEP has the best performance in most of the cases.

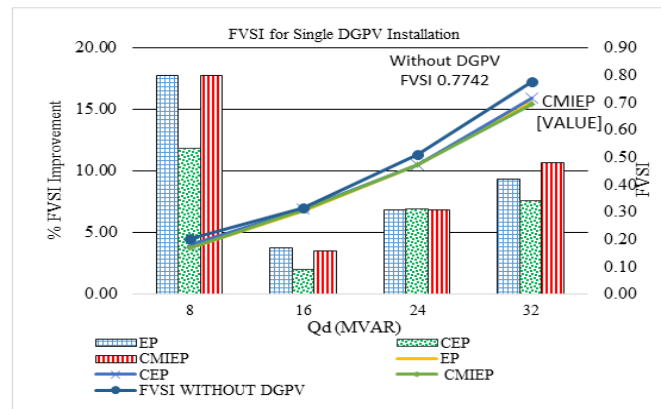


Figure 2. Comparison of FVSI using different algorithms for single DGPV installation

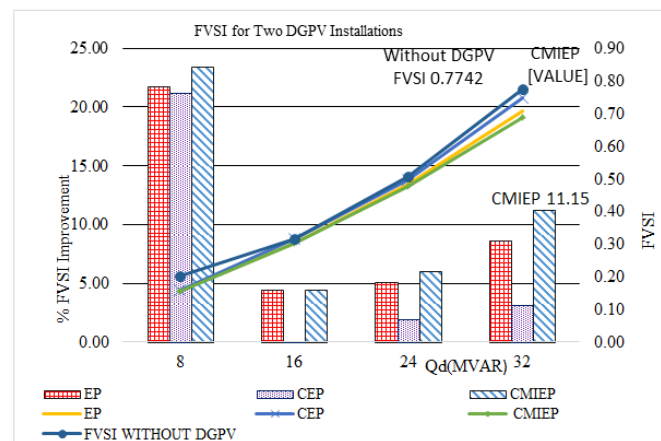


Figure 3. Comparison of FVSI using different algorithms for 2 DGPV installations

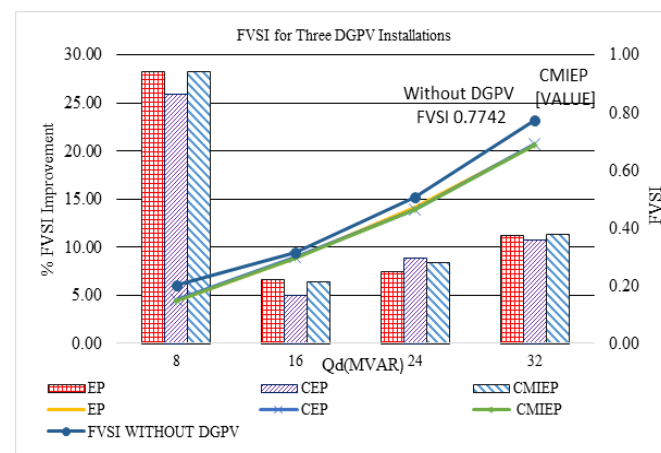


Figure 4. Comparison of FVSI using different algorithms for 3 DGPV installations

#### 4.4.1. Effect of Number of DGPV Installation of the Distribution System

Maximum benefits from the DGPV placement can be derived by considering the impact of the DGPV installation into the power system network. Number of DGPV installations is one of the important factors to be considered before the installation. This is to significantly analyze the impact of number of DGPV on FVSI reduction. Table 1 tabulates the results single unit, two units and three units DGPV installation optimized using CMIEP. It is shown that the losses are reduced when the number of DGPV installation is increased. This is indicated by the lowest losses value which is 7.5998 MW experienced by the system when three DGPV installed with 16 MVAR subjected to Bus 30.

Table 1. FVSI reduction and active power losses for multi-DGPV installations using CMIEP

Reactive Load at Bus 30 (MVAR)	1 DGPV		2 DGPV		3 DGPV	
	FVSI Reduction (%)	Losses (MW)	FVSI Reduction (%)	Losses (MW)	FVSI Reduction (%)	Losses (MW)
8	17.73	11.6815	23.39	9.0500	28.26	7.8571
16	3.43	16.2205	4.39	8.6638	6.42	7.5998
24	6.79	15.4902	5.95	9.6162	8.42	8.5259
32	10.59	18.4814	11.15	12.5456	11.34	11.1262

#### 4.4.2 Effect of DGPV on Voltage Condition

The effect of DGPV installation on voltage stability condition can be demonstrated by the reduction of FVSI values presented in Figure 4 to Figure 6. Based on Table 1, the percentage of FVSI reduction is achieved at highest reduction which is 17.73% when the reactive loading condition is 8MVAR. With the optimum location and sizing of DGPV as shown in Table 2, overall voltage profile is gradually improved. Additionally, CMIEP tabulates the most consistent solutions. It can be observed Bus 27 is always the best candidate for DGPV installation regardless the number of DGPV.

Table 2. Optimal location and sizing of DGPV when Bus 30 loaded with 32 MVAR for EP, CEP and CMIEP

No. of DGPV	EP		CEP		CMIEP	
	Location (Bus)	Size (MW)	Location (Bus)	Size (MW)	Location (Bus)	Size (MW)
1	27	38.9681	25	39.9515	27	58.0515
2	23	54.2846	17	41.2931	27	52.4677
	30	21.4279	4	42.6142	7	51.7722
3	7	55.4604	28	54.8685	27	59.53632
	16	13.0282	7	15.4660	7	37.95911
	27	55.2327	27	26.4855	15	36.13959

## 5. Conclusion

This paper has presented the chaotic mutation immune evolutionary programming (CMIEP) for voltage security with the presence of DGPV. In this study, a new approach for optimum DGPV location and sizing for the minimization of FVSI is developed. CMIEP algorithm is also proposed to solve the single objective with multi-constraints problem. Results obtained from the study revealed that the proposed CMIEP techniques outperformed EP and CEP to achieve significantly high FVSI reduction. The proposed algorithm shows that with three DGPV units the FVSI can improve up to 28% from its original value. Moreover, the power losses also significantly improved.

## Acknowledgement

The authors would like to acknowledge The Institute of Research Management and Innovation (IRMI) UiTM, Shah Alam, Selangor, Malaysia and Ministry of Higher Education (MOHE) for the financial support of this research. This research is supported by MOHE under

the Research Acculturation Grant Scheme (RAGS) with project code: 600-RMI/RAGS 5/3 (187/2014).

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