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Analysis of Error Integral Performance Indexes in Grid Connected Photovoltaic System through PI Controller for Improving DC Link Voltage by Metaheuristic and Direct Search Methods

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Abstract – *This article presents DC Link (DCL) voltage regulation of Grid Connected Photovoltaic System (GCPS). The three-phase DC/AC GCPS system comprises two primary control loops: an exterior loop for managing the DCL voltage and an interior loop for regulating inverter current. The primary element of every control loop is the Proportional-Integral (PI) controller, and determining the ideal gains for it is a difficult undertaking. To accomplish this study, Genetic algorithm (GA), Simulated annealing (SA), and Pattern Search (PS) are implemented to optimize the PI gains by taking into account numerous objective functions based on such as Integral Absolute Error (IAE), Integral Time Absolute Error (ITAE), Integral Square Error (ISE) and Integral Time Square Error (ITSE). This comparison approach offers an excellent concept for experts to elect a right error criterion.*

Keywords – Genetic Algorithm, Metaheuristic Techniques, *Pattern search, PI Controller, Simulated Annealing*

1. INTRODUCTION

Growing worldwide energy need has prompted the world to harness solar energy as an alternative energy resource due to its abundant obtainability, limitless in environment, and environmental cleanliness by [1]. Photovoltaic (PV) systems are growing in popularity as a clean and sustainable energy source due to their beneficial to the environment nature and promising long-term economic potential by [2]. Although the main barrier faced by GCPV systems is that, the voltage of the DCL is disturbed by predominant fluctuations in environmental variables such as temperature and irradiance. It is essential to regulate the DCL voltage in accordance with sun irradiation and temperature by [3]. PI controllers are utilized to maintain the desired DCL voltage and regulate the inverter current in inverter-based grid connected system. However, it faces challenges by issues pertaining to the accurate selection of the PI parameters The optimization strategies seek to optimize the constraints of the PI controllers to augment the DCL voltage of the PV system by [4]. This study implements GA, PS, and SA to optimize the conventional controller gains used for regulating the DCL voltage of the GCPV scheme. The optimization is performed by considering different cost functions based on IAE, ITAE, ISE and ITSE. Additionally, the analysis includes the examination of various cost functions in relation to the number of iterations.

2. SYSTEM CONFIGURATION

The PV array has a total active power of 100.7 kW. It operates under environmental parameters of 1000 W/sqm solar irradiation and a temperature of 25^0C. The PV array block is composed of 47 branches connected in parallel, with each branch containing 10 PV modules. The photovoltaic (PV) source is linked to a boost converter that produces a 600 V output. The boost converter has been controlled using Maximum Power Point Tracking (MPPT) centered on the Perturb and Observe technique. Inverter transforms DCL voltage value of 600 V into an alternating current (AC) value of 440 V. The following stage consists of a (L-C) filter, while the last phase is the electrical grid, as depicted in Figure 1. The control technique implemented on the inverter, as depicted in Fig. 2, comprises two control loops. The primary control loop is designed to manage the DCL voltage of the system, while the secondary loop controls the grid current. The primary element of every control loop is the PI controller and determining the ideal gains for it is a challenging process.

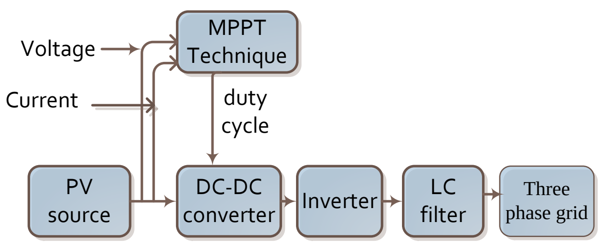

Fig. 1. PV system connected to grid.

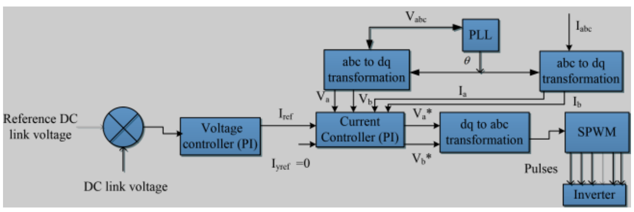

Fig. 2. Control strategy of inverter.

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3. OPTIMIZATION TECHNIQUES FOR PI CONTROLLER

The boundaries of PI controller are optimized by GA, PS, SA with various cost functions. The cost function is to minimize the error between outer voltage control loop and current control loop.

3.1 *Various Cost Functions*

The GA,PS and SA was employed to tune PI because of its optimization capability to manage with the objective function. Some cost function which employed in optimal tuning of PI given below. The e1(t) is the difference between reference and DC link voltage, e2(t) is the difference between reference current and direct component of current and e3(t) is the difference between reference reactive component of current and quadrature component of current and t is the simulation time in seconds.

$$e1(t) = V_{ref} - V_{DC} \tag{1}$$

$$e2(t) = I_{xref} - I_{x} \tag{2}$$

$$e3(t) = I_{yref} - I_{y} \tag{3}$$

$$IAE = \int_0^t \left|(e_1 + e_2 + e_3)\right| dt \tag{4}$$

$$ISE = \int_0^t \left|(e_1 + e_2 + e_3)\right|^2 dt \tag{5}$$

$$ITAE = \int_0^t t\left|(e_1 + e_2 + e_3)\right| dt \tag{6}$$

$$ITSE = \int_0^t t\left|(e_1 + e_2 + e_3)\right|^2 dt \tag{7}$$

3.2 *Genetic Algorithm*

The primary concept in GA is to utilize the capabilities of evolutionary process to address optimization challenges. Genetic Algorithm (GA) is an optimization technique that utilizes principles from natural selection theory to solve both constrained and unconstrained optimization problems by [5].

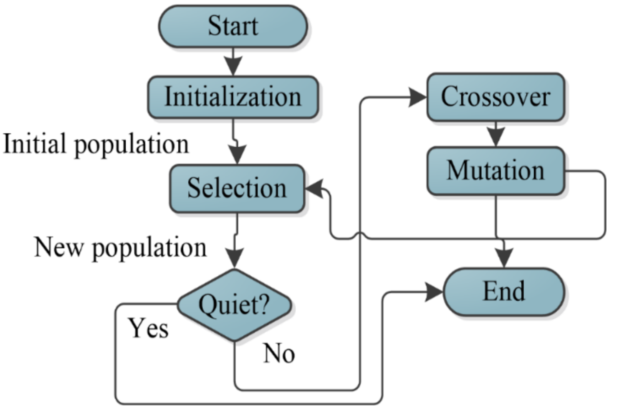

Fig. 3. Flow chart of genetic algorithm.

3.3 *Pattern Search Technique*

The PS scheme is an approach for deterministic optimization applications. The PS considers both exploratory and patterned movements. During exploratory movement, every sample travels towards rising the cost function, and the vector sum of the exploratory move is explained as a pattern. During the pattern movement step, each sample undergoes a displacement in the way of the pattern by [6].

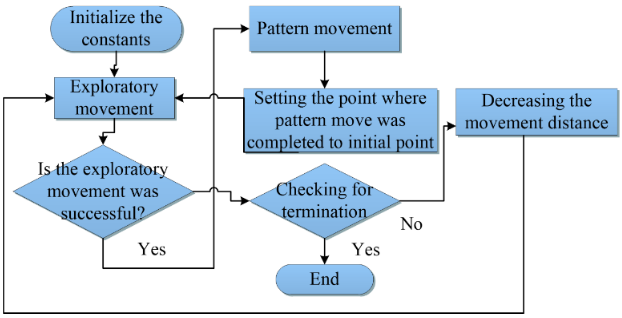

Fig. 4 Flow chart of pattern search technique.

3.4 *Simulated Annealing*

Simulated annealing (SA) is a local search algorithm. The process simulates the annealing process applied in metallurgy to find the global optimum of an optimization problem. It utilizes temperature as a means to regulate the search by [7].

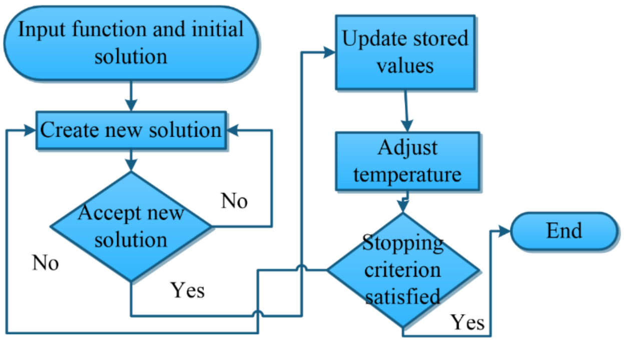

Fig. 5 Flow chart of simulated annealing.

4. RESULTS

This section demonstrates the dynamic performance of the DCL voltage of the GCPS system when the PI parameters are achieved through manual tuning, as well as using the GA, PS, and SA algorithms. It also compares different cost functions with the number of iterations.

4.1 Comparative Analysis of DC Link Voltage

The irradiance varies at t = 0.1 s from 1000 Watt/sqm to 400 Watt/sqm. Fig. 6 shows a comparison of DC link voltage without optimized and optimized by GA, PS and SA techniques respectively. As can be seen, the maximum overshoot in voltage 828.9 V, 844.8 V and 869.4 V and in percentage 38.33, 40.75 and 44.9 respectively optimized by GA, PS and SA respectively. It can be observed from below figure settling time of the PI controller is 0.036 s, 0.06 s and 0.0039 s when optimized by GA, PS and SA as well as rise time of the DC link voltage 0.0057s, 0.0055s and 0.005s respectively.

The peak time of the DC link voltage is 0.0086s, 0.0086s and 0.0083s respectively when optimized by GA, PS and SA. Below figure clearly shows at t= 0.1 s when irradiance is changed from 1000 Watt/sqm to 400 Watt/sqm the change in DC link voltage is almost 50 and when PI controller is without optimized and no change in DC link voltage with optimization techniques.

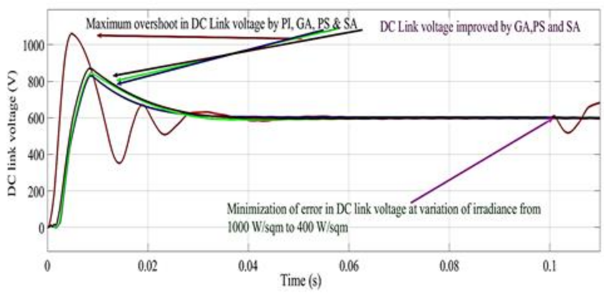

Fig. 6. Comparative analysis of DC link voltage by GA, PS & SA.

4.2 Cost Function Analysis with Iterations in Genetic Algorithm

The optimizations have implemented using different cost functions. In this paper when PV system is optimized by GA for improving DC link voltage the population size is taken as 25 and no. of generation is 50. The results show that IAE and ITAE have less cost function value than ISE and ITSE. Minimum cost function value in GA is 0.275572 when cost function is based on ITAE error criterion as shown in Fig. 10. When error criterion is based on ITAE the cost function is converge at 8th iteration.

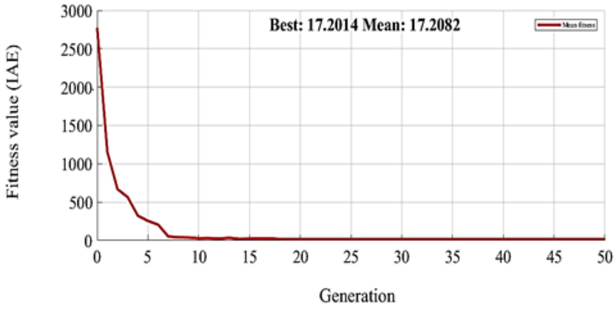

Fig. 7. Cost function analysis based on IAE in GA with iterations.

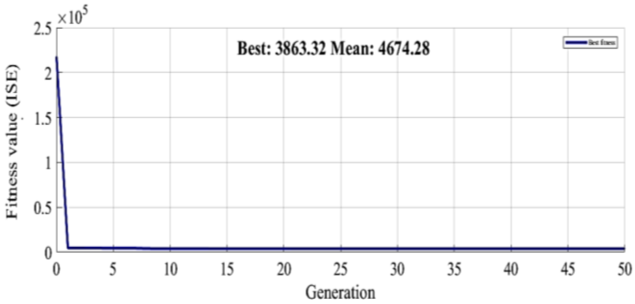

Fig. 8. Cost function analysis based on ISE in GA with iterations.

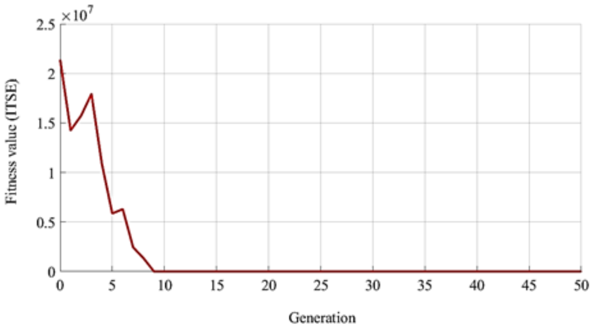

Fig. 9. Cost function analysis based on ITSE in GA with iterations.

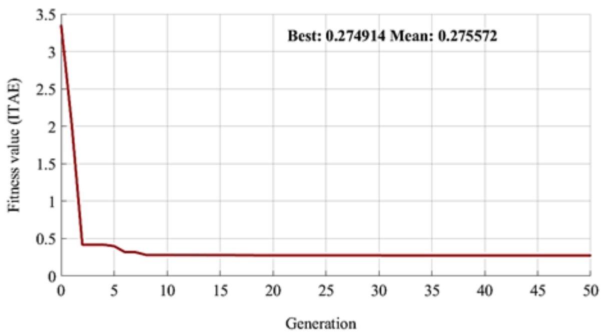

Fig. 10. Cost function analysis based on ITAE in GA with iterations.

4.3 Cost Function Analysis with Iterations in Pattern Search Algorithm

The optimizations have implemented using different cost functions. In this paper when PV system is optimized by PS the number of iterations is 50. The results show that IAE and ITAE have less cost function value than ISE and ITSE. Minimum cost function value in PS is 0.408638 when cost function is based on ITAE error criterion as shown in Fig. 14. When error criterion is based on ITAE the cost function is converge at around 9th iteration.

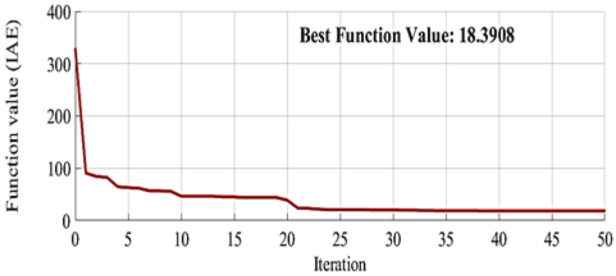

Fig. 11. Cost function analysis based on IAE in PS with iterations.

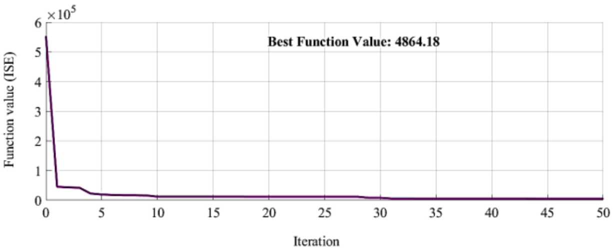

Fig. 12. Cost function analysis based on ISE in PS with iterations.

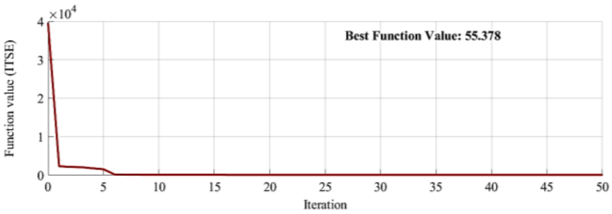

Fig. 13. Cost function analysis based on ITSE in PS with iterations.

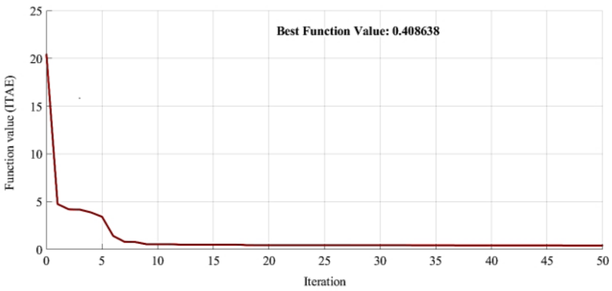

Fig. 14. Cost function analysis based on ITAE in PS with iterations.

4.4 Cost Function Analysis with Iterations in Simulated Annealing Algorithm

The optimizations have implemented using different cost functions. In this paper when PV system is optimized by SA the number of iterations is 50. The results shows that IAE and ITAE have less cost function value than ISE and ITSE. Minimum cost function value in PS is 0.506244 when cost function is based on ITAE error criterion as shown in Fig. 18. When error criterion is based on ITAE the cost function is converge at 32^{nd} iteration.

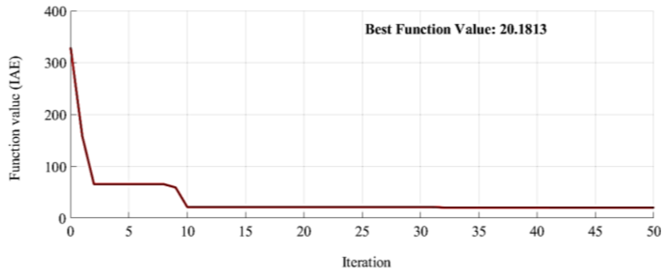

Fig. 15. Cost function analysis based on IAE in SA with iterations.

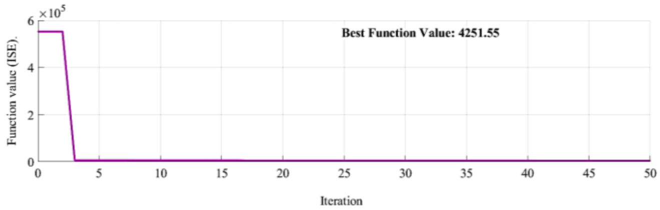

Fig. 16. Cost function analysis based on ISE in SA with iterations.

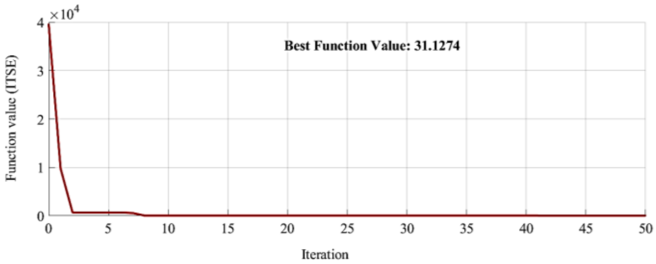

Fig. 17. Cost function analysis based on ITSE in SA with iterations.

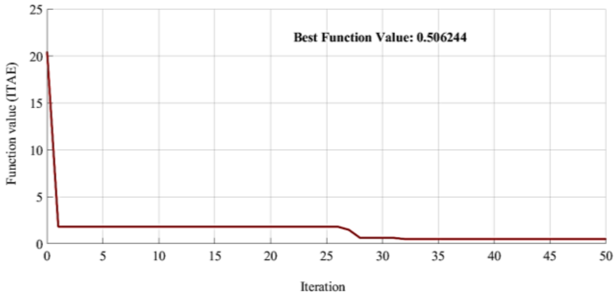

Fig. 18. Cost function analysis based on ITAE in SA with iterations.

5. CONCLUSION

Selecting the correct error integral performance indexes is crucial when employing optimization techniques such as Genetic Algorithms (GA), Particle Swarm (PS), and Simulated Annealing (SA). The purpose of using this error integral performance indexes in this research was to optimize the proportional-integral (PI) gains in the grid-connected photovoltaic (GCPV) system in order to achieve an improvement in the DCL voltage. The error integral performance indexes based on IAE, ISE, ITSE, and ITAE used in this research. In terms of cost function minimization, GA demonstrates its superiority over PS and SA. ITAE and IAE have better cost function minimization as compared to ISE and ITSE in GA, SA as well as PS optimization techniques. GA tuned system utilizing all performance indices has demonstrated sharp control responsiveness and strong resilience to dynamic uncertainties such as fluctuating irradiance in this study. Future work will include a GA-SA and GA-PS optimization techniques based on all error criterion used in this paper. Also, we will suggest replacing PI controller by FOPI controller.

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