# New Technique for Voltage Tracking Control of a Boost Converter Based on the PSO Algorithm and LTspice

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***Abstract* – In this paper, a new technique is proposed to design a Modified PID (MPID) controller for a Boost converter. An interface between LTspice and MATLAB is carried out to implement the Particle Swarm Optimization (PSO) algorithm. The PSO algorithm which has the appropriate capability to find out the optimal solutions is run in MATLAB while it is interfaced with LTspice for simulation of the circuit using actual component models obtained from manufacturers. The PSO is utilized to solve the optimization problem in order to find the optimal parameters of MPID and PID controllers. The performances of the controllers are evaluated for a wide range of operating conditions and different disturbances. The comprehensive simulation results demonstrate the effectiveness and robustness of the proposed method which are also explained through some performance indices.**

***Keywords* – DC-DC power converters, Particle Swarm Optimization, LTspice, and Modified PID**

## I. Introduction

Although different types of DC-DC converters are widely used for traditional applications such as DC motor drives, DC power supplies, telecommunications and so on [1], nowadays, industry is more and more dependent on power converters due to dramatic expansion of renewable energy sources. This is due to the fact that not only power generated by renewable energy sources like solar cells is always fluctuating, due for example to the changes in the atmospheric condition, but the loads are also continuously changing requiring converters to stabilize the output voltages [2]. Among different types of converters [1], the step-up commonly known as Boost converter [3] is one of the basic DC-DC converter topologies. As its name implies, this converter is able to increase and regulate the output voltage at a desired level.

From control point of view, in some cases, it is necessary to design a converter in order to provide voltage that should satisfy to a reference command. In other words, despite the loading and input voltage variations, generated voltage by converter should track a reference voltage as fast as possible with appropriate transient and steady state error [4, 5]. Since problems of adjustment of output voltage have been an interesting issue for many years, different methods such as model predictive controller [6], Neural Network Control [7], Intelligences Techniques [8, 9] have been proposed in the literature to control the converters. Some of these control methods are easily designed and are simple but are not so effective and robust, while some others can be effective but they are too complicated [10, 11] to implement [12].

Most of the mentioned controllers are designed and simulated based on the approximate dynamic model for the specified Boost converter which is derived from linearization of state space averaging model as the common approach for modelling the various types of DC-DC converters [5]. Considering some assumptions and simplifications to derive small signal model, it cannot adequately describe the system real behavior. In addition, using linear model depends on the operating point of the system. So, the operating point might be changed by varying the input DC voltage, reference signal and load characteristics and consequently the performance of the system can be affected by these variations. In some studies like [12, 13] MATLAB/Simulink environment is used for the simulation of converters and different controllers. Since in MATLAB only generic elements are typically used for transistors and diodes, the results are not so close to reality.

Overall, compared to other controllers, PID controller is the most practical and popular among the controllers used in industry due to their simplicity in design and low price, together with of showing satisfactory performances [2, 14]. However, several attempts have been made to enhance the quality and robustness of these types of controllers [5].

In this paper a new technique is proposed for optimal design of Modified PID (MPID) and PID controllers for Boost converter by PSO algorithm. The PSO algorithm in MATLAB is employed to find out the optimal parameters of a MPID controller designed for Boost converter in LTspice. MATLAB is interfaced with LTspice to access the Boost converter circuit. Using LTspice allows having realistic results because it provides a wide component database with manufacturer specifications. In addition, this software is able to use various component models that are downloadable from manufactures' websites [15, 16]. In fact, this new approach combines the advantages of LTspice for simulation of different circuit configurations using actual component obtained from manufactures' models with advanced intelligent techniques capabilities from PSO in MATLAB. This bidirectional interface has an ability to transfer the data between simulated circuit in LTspice and MATLAB so that the code in MATLAB not only can control the PSO and interface to LTspice but it also is able to modify the simulated circuit configuration in each iteration of PSO algorithm. To evaluate

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the effectiveness and robustness of the proposed technique, different disturbances in input voltage and load are applied to system and the simulation results are presented and discussed.

## II. Modelling and Analysis of Boost Converter

Fig. 1 shows a basic circuit of a Boost converter consists of a power MOSFET as a switching transistor connected to the flywheel circuit ($D_1$, $L_1$ and $C_1$). As its name implies, this converter is capable of providing greater output voltage compared to its input voltage [1]. In this case, an N-channel Power MOSFET- IRFZ44 is used as a switch operated at a frequency of 50 kHz. In addition, compared to using a conventional diode, a Schottky diode is modeled because of its lower forward drop, lower power dissipation and high efficiency [18]. Finally, the values of inductor, capacitor and load are chosen 820uH, 120uF and 25 Ω, respectively. To get deeper understanding of how the Boost converter works at higher voltage, the performance of Boost converter can be expressed by its transfer function as follows [1, 17]:

$$H(D) = \frac{V_{output}}{V_{Input}} = \frac{1}{1-D} = \frac{1}{D'} \quad (1)$$

Therefore, the Boost converter can be imagined as a DC transformer where its turn ratio can be controlled by adjusting the duty ratio ($D$) of the MOSFET.

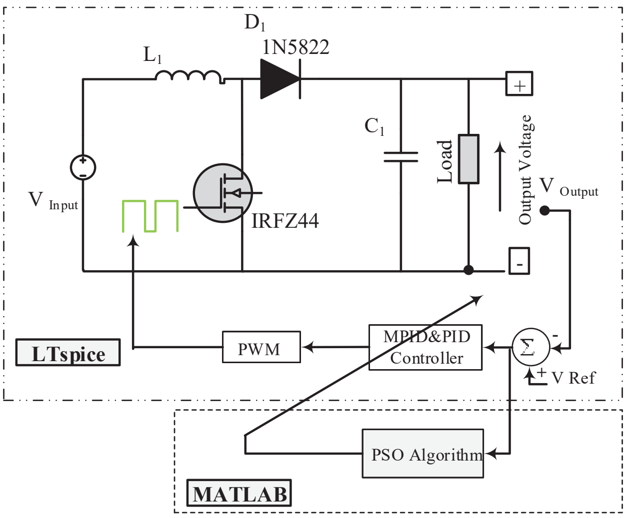


Fig. 1. Boost converter with proposed technique

## III. Particle Swarm Optimization Algorithm

In 1995, Eberhart and Kennedy introduced a method called PSO, which was based on stochastic optimization technique [19, 20]. This algorithm, which its basic idea came from imitating the social behavior of birds and fishes to look for food, is formed from a population of particles. Fig. 2 shows PSO flowchart in order to find the solution to optimization problem and also indicates how it moves toward the optimal position through the search space. As can be seen in this figure, each particle needs to be updated by two "best values" (namely $p_{best}$ and $g_{best}$) at each iteration. In this algorithm, two factors of position $x_i = (x_{i1}, x_{i2},..., x_{in})$ and velocity $v_i = (v_{i1}, v_{i2},..., v_{in})$ display the state of each particle. The $p_{best}$, which is the latest achievement, represents the position vector of the best fitness (as the local best position). The fitness function value $p_i = (p_{i1}, p_{i2},..., p_{in})$ is recorded as well. Each particle in the population can determine another "best value" position which is tracked by the particle swarm optimizer as the best position. This best position called $g_{best}$ is the current global best $p_g = (p_{g1}, p_{g2}, ..., p_{gn})$. At each time step, when the two best values become clear, the velocity and position of the particle will be updated according to (2) and (3), respectively [21].

$$v_i(k+1) = w v_i(k) + r_1 c_1 [g_{besti} - x_i(k)] + r_2 c_2 [p_{besti} - x_i(k)] \quad (2)$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (3)$$

where $x_i(k)$ is the position of the current particle, $v_i(k+1)$ is the i^th^ the particle̓ s velocity at $(k+1)^{th}$ iteration. $c_1$ and $c_2$ are self-confidence and the swarm confidence of a particle which generally take values between 1.5 and 2.5. $r_1$ and $r_2$ are considered random numbers between 0 and 1, and $w$ is the inertia factor that is between 1 and 0 (downward) ,according to the iteration number.

As soon as the predetermined termination condition is gained, $p_g$ will be the optimal value found. As described before, some parameters such as accelerating constants, inertia weight, iterations and velocity and position of each particle with minimum and maximum permissible values are essential for PSO algorithms implementation. Based on Fig. 2, fitness function is formulated and evaluated with the initial swarm population subject to the already defined constraints, which find the local best fitness of each particle and the global best fitness of the swarm. Present fitness and the local best fitness of each particle are the same at the first iteration. All the particles̓ s positions, velocity and Inertia weighting function in the swarm are updated as per (2) and (3). The updated swarm evaluates the fitness function and then the present local fitness is compared with the local best fitness. After the comparison, if the local best fitness becomes more than the present fitness, then the local best fitness will be updated. Afterward the global best fitness of the swarm is found. If the previous global fitness is more than the present global fitness, the global fitness function will be updated. The optimization process is executed continuously and it would be stopped either all the particles obtain the global best position or the maximum number of iterations is passed.

## IV. Modified PID Controller for Boost Converter

While new and effective designs and theories are continually extended in the subject of control, PID controllers as a three-term controllers are still very popular in industry due to its simplicity in design and good performance [14, 22]. The PID modeled in this paper is described by following equation:

$$G(s) = K_p + \frac{K_i}{S} + K_d S \qquad (4)$$

where $K_p$, $K_i$ and $K_d$ are the proportional gain, the integral gain and the derivative gain, respectively.

Advantages of this type of controller cause continuous attempts to be conducted so as to enhance the robustness and effectiveness of them. The given PID structure in equation (4) is rarely adopted in practical cases owning to a few problems [14]. Hence, the PID controller is often modified as follow:

$$G(s) = K_p\left(1 + \frac{1}{T_i S} + \frac{T_d S}{\frac{T_d}{N} S + 1}\right) \qquad (5)$$

where $K_P$ is the proportional gain, $T_i$ is the integral time constant and $T_d$ is the derivative time constant. In addition, $N$ generally assumes a value between 1 and 33 [14, 23].

## V. Interaction Between PSO and Simulated Model

Fig. 3 demonstrates how the PSO algorithm (MATLAB) interacts with the model in the LTspice during the optimization process. This interface allows data to transfer bi-directionally between PSO algorithm in MATLAB and the simulated circuit in LTspice. Based on this technique, the bidirectional interface performs in a closed loop so that the optimization process will be continued automatically and without the need to open the LTspice file manually. The following steps are considered in design procedure to create the mentioned interaction: 1) Open the simulated model in LTspice by using MATLAB; 2) Set the given initial parameters by PSO in LTspice model directly from MATLAB; 3) Access to LTspice by MATLAB and simulate the circuit modeled in LTspice; 4) Read the output results from LTspice [24, 25] and calculate the fitness function in MATLAB for PSO; 5) Perform PSO algorithm to set new values of controller parameters in LTspice; 6) Repeat the step 3 in order to obtain the optimal parameters.

As shown in Fig. 3, first of all the initial parameters of the PSO algorithm are set. Then, the simulation procedure is conducted based on interaction between simulated model and PSO, the results in data are allowed to flow towards MATLAB. Afterwards, the output results started to be analyzed by PSO so as to find the optimal parameters for controllers. The whole process repeats until a satisfactory consequence appears.

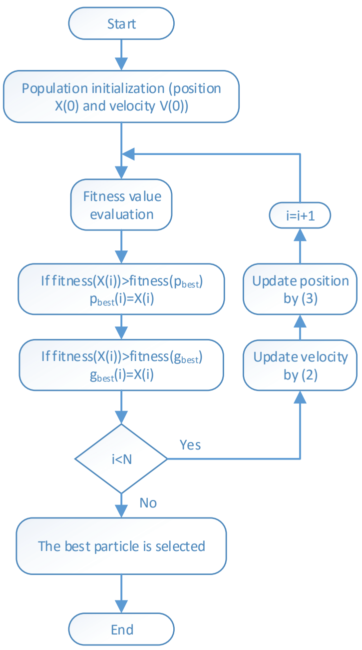

Fig. 2. Flowchart of PSO algorithm

## VI. Simulation Results

In this section, the proposed technique is employed for PID and MPID controllers in order to improve the performance of the Boost converter. In fact, PSO algorithm is used to find the optimal parameters for these controllers based on minimizing the fitness function given by following equation:

$$Fitness\ Function = \int_0^{Tsim} t.\ |e(t)|\ dt \qquad (6)$$

where $T_{sim}$ is the simulation time and $e(t)$ means the difference between desired and resulted voltage.

In addition to given fitness function for PSO, the following parameters are set in this optimization method: 1) The number of variables for optimization is 3 and 4 for PID and MPID controllers, respectively; 2) The number of particles is 10; 3) $c_1$=1.8 and $c_2$=2.2; 4) Iteration is considered 100.

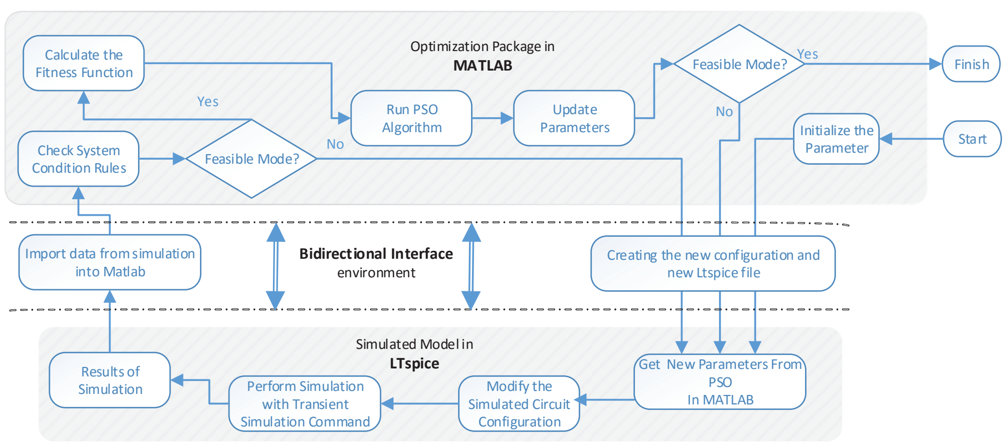

Fig. 3. Interaction between PSO optimization Algorithm and simulated circuit in LTspice

In the first step, PSO starts to evaluate the fitness function base on the initial population which is generated between minimum and maximum values for each parameter. Then, it tries to update the values and go toward the optimal position. Fig. 4 shows the initial and the final solution for the mentioned PSO for MPID controller approach. Furthermore, Fig. 5 depicts how the fitness function is changing during this process according to the number of iterations. Table I lists the optimal parameters found by PSO for controllers using proposed fitness function. In this paper, the performance of mentioned Boost converter is tested for various operating conditions. The nominal input voltage of converter is set to 15 V with a variation of ± 33 % and the nominal output voltage is set to 25 V. To evaluate the load variations effect on the converter, the output power range is considered 25 W ± 60%. In the Fig. 6 the step responses of the Boost converter based on MPID and PID are compared in the nominal condition, and also to assess the robustness of the proposed technique, the tracking of a specific reference (which is changing by time) are shown in Fig. 7. According to Fig. 6, it is clearly seen that MPID controller can obtain better response compared to PID controller. For more analysis, it can be noticed when MPID controller is employed for the Boost converter, the settling time is decreased by 79% in comparison with using PID controller. In addition, there are a significant reduction of 83% and 72% in the amount of overshoot and undershoot for MPID approach compared to PID controller. As shown in Fig. 7, in despite of varying the reference voltage the system has still the great ability to track the desired voltage as fast as possible.

To assess the effectiveness and robustness of the proposed technique, simulations are carried out for four different conditions. The operating conditions including parameter variations and external disturbances are considered as follows:

- Scenario 1; Input voltage is 15V (nominal voltage) and the load is changing between 25Ω (P=25W) and 60Ω (P ≈ 10W).
- Scenario 2; Input voltage is 15V (nominal voltage) and the load is changing between 25Ω (P=25W) and 15Ω (P ≈ 42W).
- Scenario 3; Input voltage variations: the load is 25Ω and the input voltage is varied between 10V and 15V.
- Scenario 4; Input voltage variations: the load is 15Ω and the input voltage is varied between 15V and 20V.

In scenario 1, the nominal voltage is applied to the Boost converter while the load is increased to 60Ω at t=25ms and after 13ms it is returned to its nominal value. The response of the system under this condition is shown in Fig. 8. Although it is obviously seen that proposed approach can greatly return back the voltage to its steady state value, it should be noticed that the MPID provides the faster settling time in comparison with PID. Similar to scenario 1, the input voltage for the converter is set at 15V while in this case, the load is changed from 25Ω to 15Ω (heavy loading) at t=25ms and it again is reached its initial value at t=38ms. The response of the converter is depicted in Fig. 9. With respect to Fig. 9, it is self-evident that the proposed technique still is able to deal with these load disturbances. Furthermore, Figs. 10 and 11 present the output voltage of the converter under scenarios 3 and 4 conditions, respectively. In the third scenario, there is a significant decrease in input voltage (15V to 10V) at t=20ms and it again is returned to its nominal value at t=35ms. Compared to previous scenario, in the last scenario, the input voltage is varied between 20V and 15V at the same time instants of the scenario 3. Based on these figures, it is reasonably clear that the output voltage can be recovered to its initial value due to good operation of proposed method. In fact, in these cases, with presence of 33 % input voltage variations at t=20ms, the converter still have the ability to handle voltage disturbances and stabilize the output voltage at the desired level.

TABLE I. Optimized Parameters

| Controllers | Parameters |
|---|---|
| MPID | $K_p$=2.49 , $T_i$=0.0006, $T_d$=0.0006, N=32 |
| PID | $K_p$=11.5 $K_i$=17 $K_d$=0.007 |

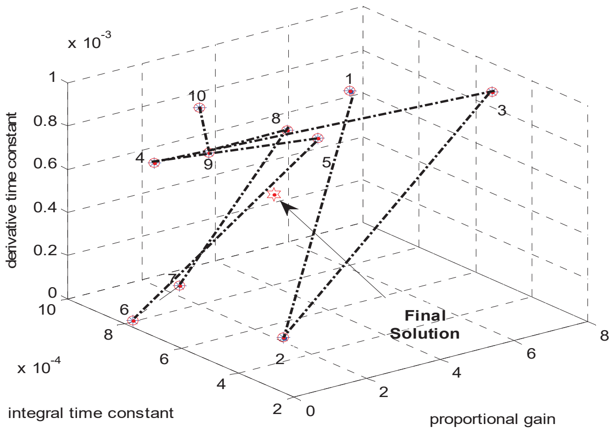


Fig. 4. Initial population and final obtained positions

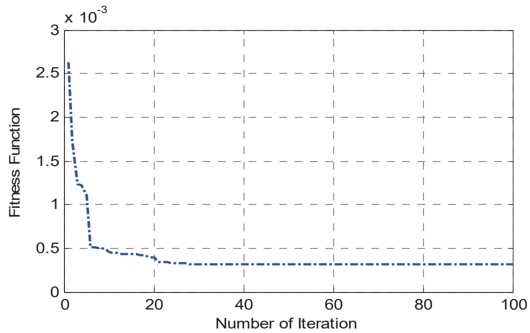


Fig. 5. Convergence of PSO optimization Algorithm

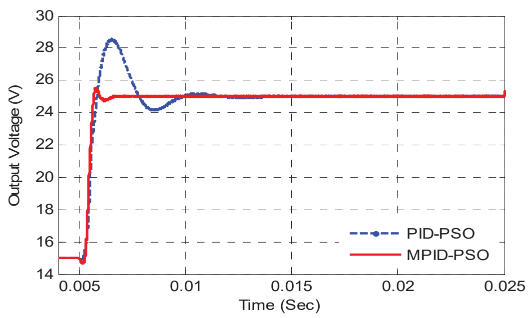


Fig. 6. Step response of Boost converter

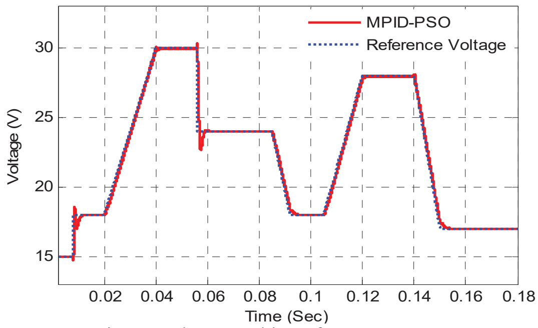

Fig. 7. Voltage tracking of Boost converter

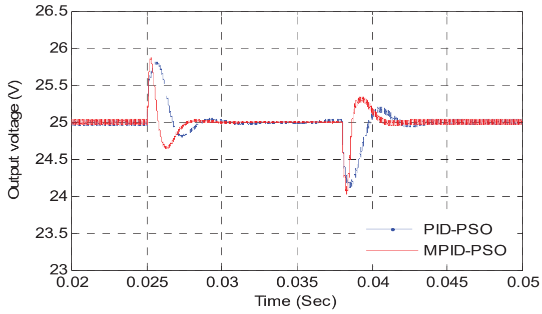

Fig. 8. Voltage response in Scenario1

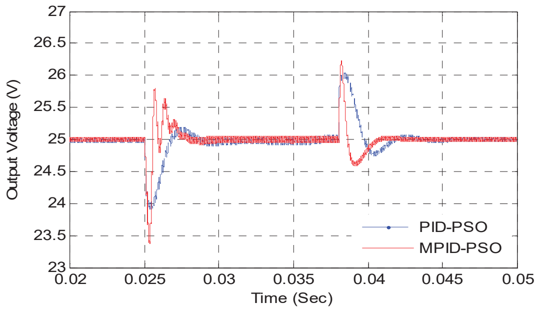

Fig. 9. Voltage response in Scenario2

To have a better analysis of proposed controllers, two performance indicators are defined as follows:

$$ITAE = 10^5 \int_{20ms}^{50ms} t.|e(t)|\, dt \qquad (7)$$

$$ITSE = 10^5 \int_{20ms}^{50ms} t.e(t)^2 dt \qquad (8)$$

where *ITAE* means the integral of the time multiplied absolute value of the error and *ITSE* is the integral of the time multiplied square of the error. Clearly, the lower value of these indicators demonstrates the better performance of the system. Besides, the settling time is considered for all scenarios to evaluate the system response under different disturbances.

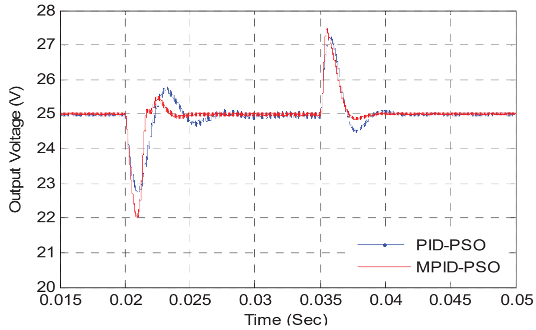

Fig. 10. Voltage response in Scenario 3

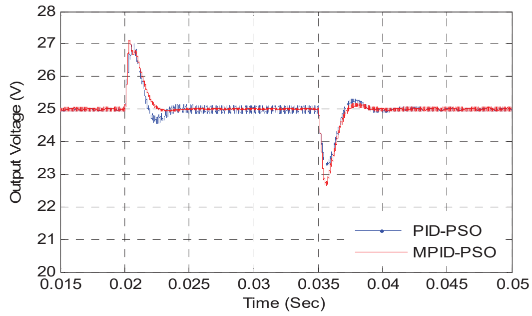

Fig. 11. Voltage response in Scenario 4

Numerical results of the effectiveness and robustness of proposed technique shown in Table II and Figs. 12 and 13. According to Table II, in the first scenario the value of ITAE for PID is 8.83, while for MPID, it is reduced by about 31% and reached 6.05. Also, the value of ITSE for MPID is decreased by approximately 45% in comparison with the value of ITSE for PID. For scenarios 2 and 3, there is a slight reduction of around 25% in the value of ITAE for MPID compared to that of PID. In the last case, although the value of ITSE for MPID is greater than PID, it can be clearly observed that MPID has low settling time (Figs. 12 and 13). With respect to above discussion and comparison, it can be concluded that performance of system based on the proposed new technique is effective and robust.

## VII. Conclusion

A new approach has been proposed to design a modified PID controller for a Boost converter. The technique combines the advantages of LTspice for simulation of converters using actual components with advanced artificial intelligence

TABLE II. Values of performance indicators ITAE and ITSE

| | Controller | Scenario 1 | | Scenario 2 | |
|---|---|---|---|---|---|
| Load Variation | | ITAE | ITSE | ITAE | ITSE |
| | MPID | 6.05 | 2.28 | 7.94 | 4.11 |
| | PID | 8.83 | 4.14 | 10.60 | 5.95 |
| Input Voltage Variation | Controller | Scenario 3 | | Scenario 4 | |
| | | ITAE | ITSE | ITAE | ITSE |
| | MPID | 18.11 | 29.36 | 16.82 | 22.17 |
| | PID | 23.71 | 29.55 | 17.36 | 16.26 |

technique provided by the PSO algorithm implemented in MATLAB. First, a Boost converter has been simulated in LTspice, and then PSO algorithm has been employed to find the optimal modified PID controller parameters. The performance of the system has been tested for a wide range of operating conditions and for different disturbances. By analyzing the system voltage response and some performance indicators, the results have clearly shown the effectiveness and robustness of the proposed method.

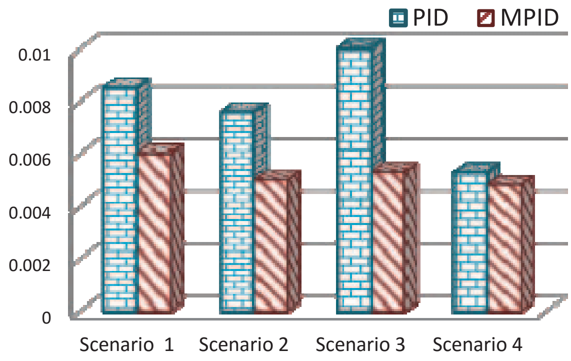


Fig 12. Settling time comparison for the initial disturbance (Sec)

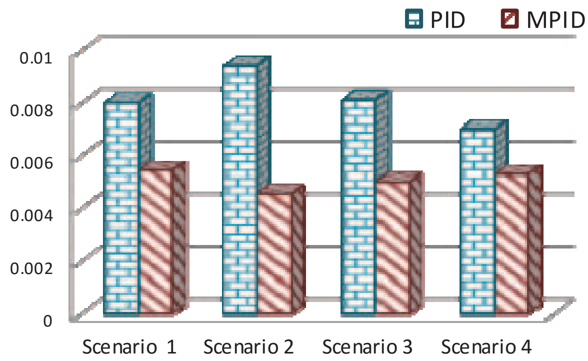


Fig 13. Settling time comparison for the second disturbance (Sec)

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