Design and Implementation of a New PWM Based Active Impedance Power Factor Correction (AIPFC)

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ABSTRACT

In this paper a new circuit for improving the input power factor is proposed. The proposed circuit is constructed based on active elements and it is called Active Impedance Power Factor Correction (AIPFC). The operation of the AIPFC is based on a PWM technique and it will be modeled and tested using a MATLAB Program (SIMULINK). In this case, the AIPFC model is installed in two different power electronics applications. The simulation results for both applications will be presented and compared with the circuit that the AIPFC is not installed. In both applications the Input Power Factor (PF$_{in}$) and the Total Harmonic Distortion (THD) will be recorded. In addition, the proposed AIPFC is implemented and tested and the experimental result will be presented.

KEYWORDS

POWER FACTOR CORRECTION (PFC), PWM BASED INVERTER, TOTAL HARMONIC DISTORTION (THD).

1. INTRODUCTION

Every year, millions and millions of notebook computers, LCD monitors and LCD televisions are produced. With such a fast growing number of these and other electronic devices using more and more power, actions must to be taken to ensure the functionality of the nationwide power grid [1-4]. In 2001, the European Union put EN61000-3-2 into effect to set the harmonic regulation standard on any power grid supplied application with power consumption over 75 watts. This essentially requires power factor correction (PFC). Therefore, power factor improvement is the growing issue of concern. Within power quality framework, one of the important aspects is reactive power control. Consumer load requires reactive power that varies incessantly and increases transmission losses while affecting voltage in the transmission network. To prevent unacceptably high voltage fluctuations or the power failures that can result, this reactive power must be compensated and kept in balance. This function has always been performed by passive elements such as reactors or capacitor, as well as combination of the two that supply inductive or capacitive reactive power. The more quickly and precisely the reactive power can be compensated, the more efficiently the various characteristics of transmissions can be controlled. Since most loads in modern electrical distribution systems are inductive, there is an ongoing interest in improving power factor. The low power factor of inductive loads robs a system of capacity and can adversely affect voltage level. As such, power factor correction through the application of capacitors, Synchronous Alternators, TCR, SVC, Power Electronic DC-DC convertors etc. is widely practiced at all system voltages. As utilities increase penalties they charge customers for low power factor,

system performance will not be the only consideration. The installation of power factor correction circuits improves system performance and saves money. In order to ensure most favorable condition for a supply system from engineering and economic standpoint it is important to have power factor as close to unity as possible. Linear loads with low power factor (such as induction motors) can be corrected with a passive network of capacitors or inductors. Non-linear loads, such as rectifiers, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise power factor. The devices for correction of power factor may be at a central substation, or spread out over a distribution system, or built into power-consuming equipment [5-23]. In this paper, a new PWM based active impedance power factor correction (AIPFC) will be designed and implemented for such non-linear loads.

2. PRINCIPLE OPERATION OF AN ACTIVE IMPEDANCE POWER FACTOR CORRECTION (AIPFC)

The principle operation of the proposed AIPFC is to generate an injecting voltage in the circuit with the phase shift of 90 degree lagging with the line current in order to get effect of capacitive impedance.

Power electronic offer a solution to supply a voltage has different phase with current in a way to give the effect of the impedance in an active way without using passive components. In addition this reduce much problem such as using a capacitor to improve power factor that cause a sub-synchronous resonance that lead to broke shaft in generators.

Figure 1 shows the block diagram of the AIPFC connected between node a and node b. It contains of five boxes that represent system to make the desired effect of the variable capacitive impedance.
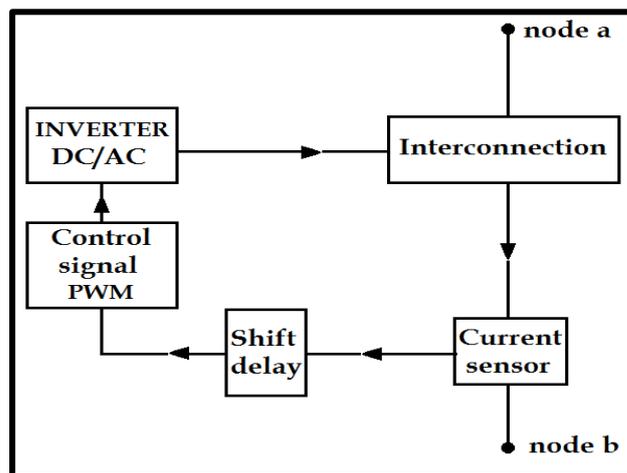

Figure 1: Block diagram of the AIPFC.

The operation of the system is starting with a current sensor to measure the zero crossing time of the current in the branch a-b and then to determine reference waveform. In this part either a current transformer can be used to measure the current in the branch a-b or a resistor with a value of 1Ω can be used to measure the voltage across it (it will be the same as a current waveform according to the ohm's law). The output signal from the current sensor circuit is then passed to the shift delay circuit box. A shift delay circuit is the main part of the system

that is used to determine the type of the impedance to be produced in that process. In this case, the output waveform from the shift delay circuit can produce the effect of three types of impedances and it will be as following:

a) 0 degree of phase shift will produce an effect of a resistive load.
b) +90 degree of phase shift will produce an effect of a capacitive load.
c) -90 degree of phase shift will produce an effect of an inductive load.

The output signal from the phase shift delay circuit is then compared with a triangular waveform to generate PWM gate signals for the inverter circuit. Finally, the output signal is injected to the main system by using a shunt transformer as shown in the circuit diagram of figure 2. Therefore, the injected voltage signal can have the effect of any type of the impedance (resistive, inductive or capacitive) in the circuit. In addition, the magnitude of the effected impedance can be varied or controlled by varying the modulation index of the PWM waveform.
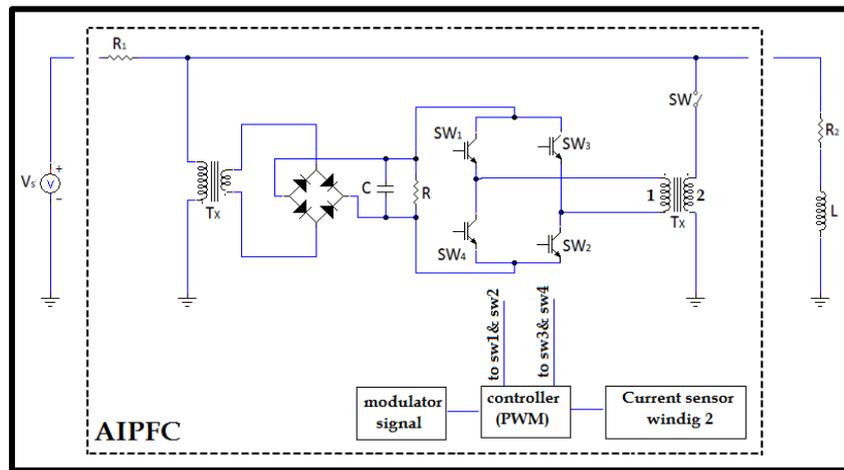

Figure 2: AIPFC circuit diagram.

3. SIMULATION RESULTS

The above proposed AIPFC circuit was tested and simulated using SIMULINK program in the following power electronics applications:

3.1 A Single Phase Phase-Angle Control with Resistive Load

Figure 3 shows a single phase phase-angle control with resistive load and AIPFC. In this case the input power factor without AIPFC can be calculated as following [24]:

$$PF_{in} = \sqrt{\left[\frac{(\pi - \alpha) + 0.5 sin2\alpha}{2\pi} \right]} \tag{1}$$

Where, α is called the firing angle of the Triac.
In addition, the total harmonic distortion (THD) can be calculated as following [24]:

$$THD = \frac{1}{V_{o1}} \sqrt{\sum_{n=2,3,\dots}^{\infty} (V_n^2)} \tag{2}$$

Table 1 shows the comparison simulation results for the circuit given in figure 3 with and without AIPEC and in case of modulation index (M) equals to 60%. It can be seen that, for each extreme value of the firing angle (α) the Input Power Factor (PF$_{in}$) has been improved. In addition, the Total Harmonic Distortion (THD) has been also improved at each extreme value of the firing angle (α). Figure 4 represents the simulation results for the circuit given in figure 3 with and without AIPEC and in case of modulation index (M) is varying. It can be seen that for all values of modulation index (M) the Input Power Factor (PF$_{in}$) has been improved at each extreme value of firing angle (α). Moreover, the Input Power Factor (PF$_{in}$) is also increases as the modulation index (M) is increasing.

Table 1: Simulation results for the circuit given in figure 3.

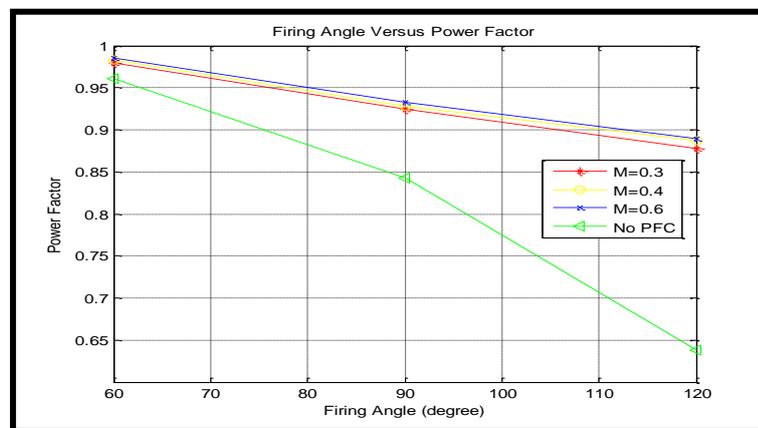| Vs=240V, R = 50Ω, M=60%				
Firing Angle (α)	PF$_{in}$ without AIPEC	PF$_{in}$ with AIPEC	THD Without AIPEC	THD With AIPEC
60º	0.9603	0.9856	37.83%	33.9%
90º	0.8427	0.933	66.62%	58.9%
120º	0.6375	0.890	96.30%	93.00%

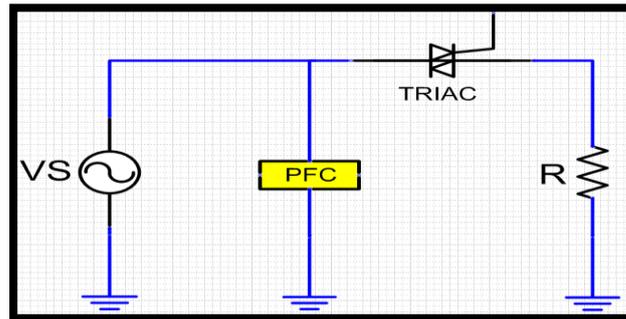Figure 3: A single phase phase-angle control with resistive load and AIPFC.

Figure 4: Simulation results for the circuit given in figure 3.

3.2 A Single Phase Phase-Angle Control with RL Load

Figure 5 shows a single phase phase-angle control with RL load and AIPFC. In this case the input power factor without AIPFC can be calculated as following [24]:

$$PF_{in} = cos\emptyset \left[\frac{\delta}{\pi} - \frac{sin\delta}{\pi cos\emptyset} cos(2\alpha + \delta + \emptyset)\right]^{0.5}$$ (3)

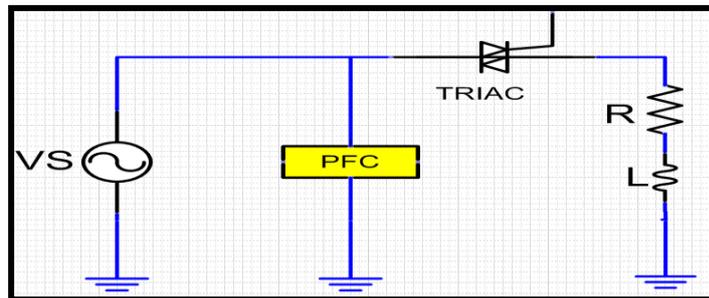Where, δ is the conduction angle of the Triac and ϕ is the load angle.

Figure 5: A single phase phase-angle control with RL load and AIPFC.

It can be seen from Table 2 and Figure 6 that the same results have been recorded when the load was resistive in terms of improving the Input Power Factor (PF_{in}) and the Total Harmonic Distortion (THD). Therefore, more improvement can be recorded if the modulation index (M) is increased and this is because the percentage of the capacitive compensation will be increased.

Table 2: Simulation results for the circuit given in figure 5.

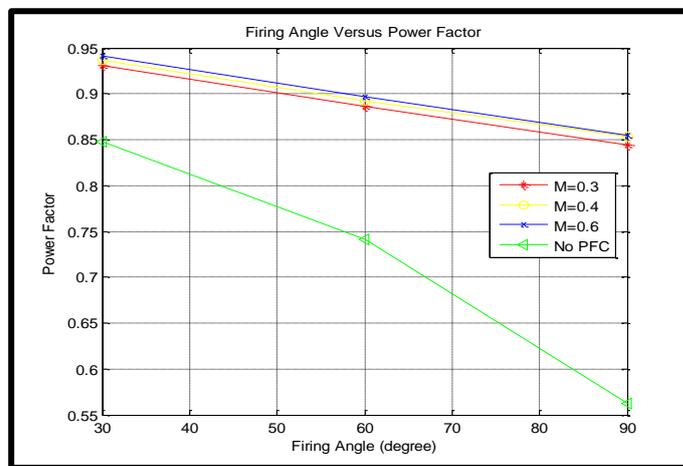| Vs=240V, R = 50Ω, L= 0.1H, M=60%				
Firing Angle (α)	PF$_{in}$ without AIPEC	PF$_{in}$ with AIPEC	THD Without AIPEC	THD With AIPEC
30º	0.847	0.941	2.96%	0.20%
60º	0.741	0.897	16.55%	14.58%
90º	0.562	0.855	38.25%	34.00%

Figure 6: Simulation results for the circuit given in figure 5.

4. IMPLEMENTATION OF AIPFC

Figure 7 represents the experimental circuit which consists of a voltage source feeding RL load with Active Impedance Power Factor Correction (AIPEC). Practically, the AIPFC consists of an Integrated Circuit, Microcontroller (PIC16F877A), Interfacing Circuit, and a Voltage Source Inverter (VSI). The operation of this figure will as following:
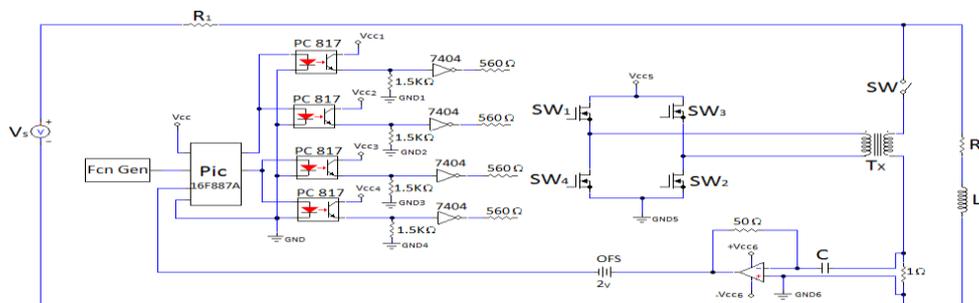

Figure 7: Experimental c ircuit with AIPFC.

4.1 Integrated Circuit

It is used to sense the current waveform from the branch at which the AIPFC is connected. This current waveform is then integrated (shifted be 90º) and connected to the input of the Microcontroller (PIC16F877A). Figure 8(a) shows the integrated circuit and figure 8(b) shows the input and output waveforms of the integrator circuit.
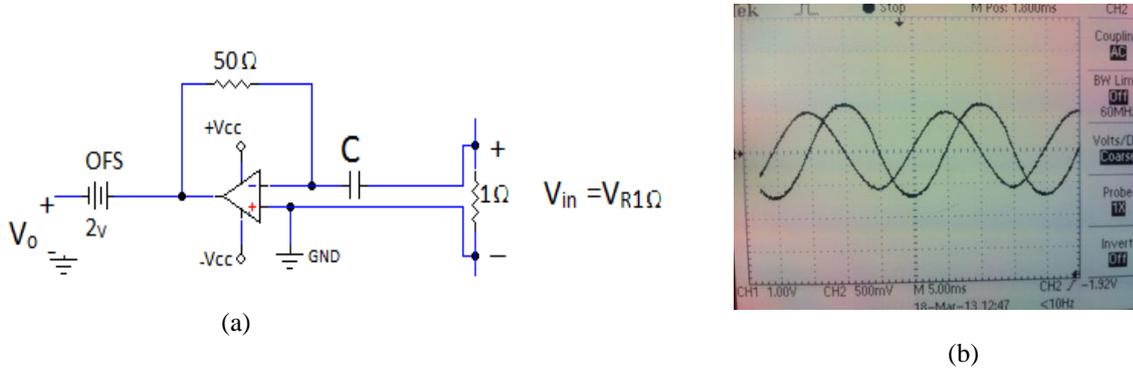

(a)

(b)

Figure 8: (a) Integrated circuit, (b) Input and output waveforms of the integrator circuit.

4.2 Microcontroller (PIC16F877A)

A microcontroller PIC16F877A chip shown in figure 9(a) has been used to generate gate signals for the inverter switches. In this case, a program written and loaded to the microcontroller in order to read the input signals from its port A and generates output signals at its ports B and C. The main function of this program is to compare between the two input signals (a triangular wave and output signal from the integrated circuit) and to generate two PWM signals at the output ports (B and C) of the microcontroller as shown in figure 9(b). In addition, the dead time between the two outputs signals generated by the microcontroller is also included in the program as shown in figure 10.
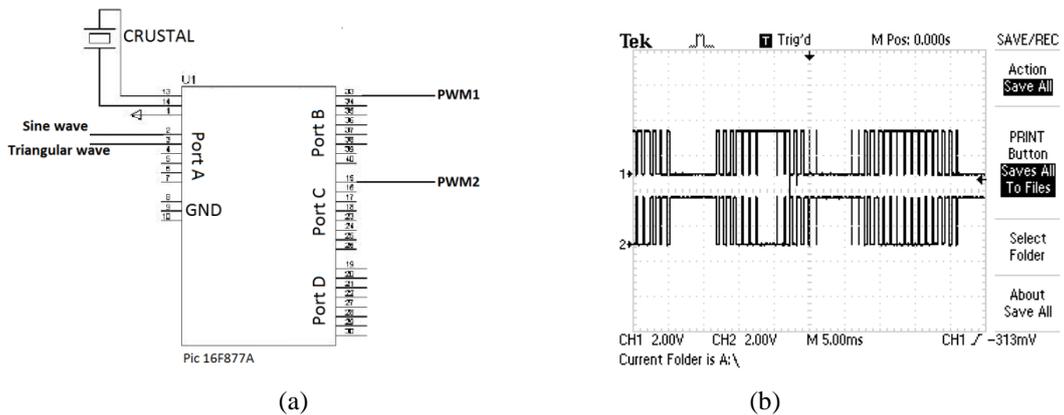

(a)

(b)

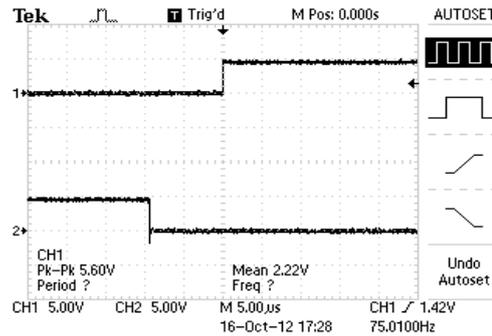Figure 9: (a) A microcontroller PIC16F877A chip, (b) Output waveforms from Ports B and C.

Figure 10: The dead time between the two outputs signals at ports B and C.

4.3 Interfacing Circuit

The interfacing circuit is used to interface the signal output from the microcontroller to the power electronics circuit (inverter). This circuit consists of two sections as shown in figure 11.
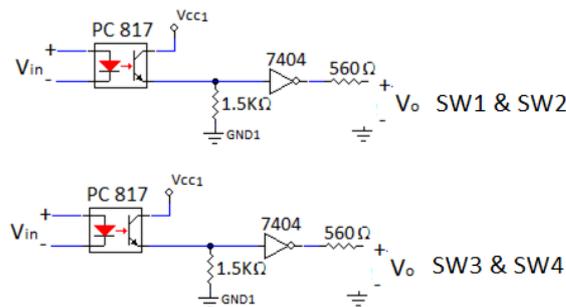

Figure 11: Interfacing Circuit

4.3.1 Opto-coupler Circuit

This circuit consists of four sets of Opto-coupler PC817. They are used to isolate the microcontroller output signals from the power electronics circuit.

4.3.2 Inverter Buffer Circuit

The second section contains the inverter buffers (IC7404) which are used to invert and boost the Opto-coupler output voltages from 5V to 15V.

4.4 Voltage Source Inverter with Its Driver Circuit

This section consists of two sets of the International Rectifier's IR2110 gate drivers. Each of these drivers is used to drive one high side and one low side of one leg of the single phase inverter. With additional components (as shown in figure 12), the IR2110 provides very fast switching speeds (approximately 35ns for the rise time and 25ns for the fall time) and low power dissipation. These drivers are operated on the bootstrap principle to handle a high switching frequency (3.2 kHz) at the IGBTs gates. Figure 13 shows the inverter output voltage waveform.
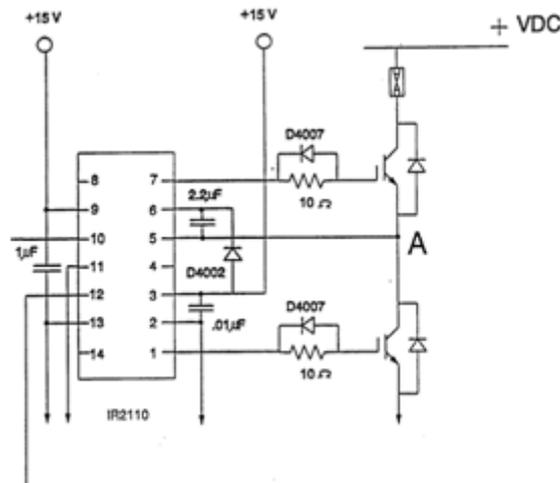
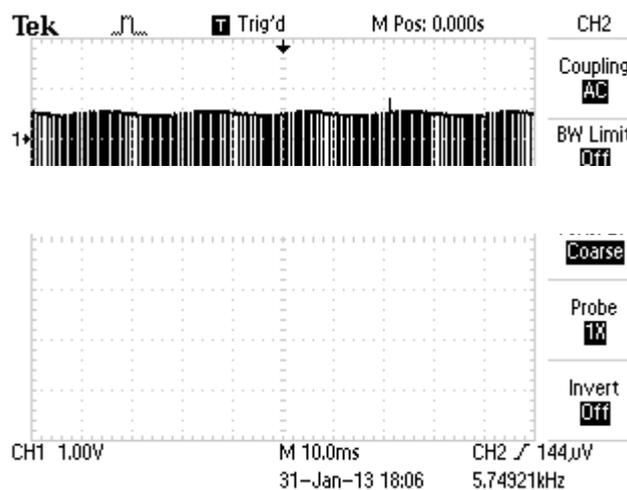Figure 12: Voltage source inverter with its driver circuit.

Figure 13: Inverter output voltage waveform.

4.5 Experimental Results

Table 3 shows the comparison experimental results for the circuit given in figure 7 with and without AIPEC and in case of modulation index (M) equals to 60%. It can be seen that, for each extreme value of the load inductance value, the Input Power Factor (PF_{in}) has been improved.

Table 3: Experimental results for the circuit given in figure 7.

Vs=240V, R = 50Ω, M=60%		
L(H)	PF$_{in}$ without AIPEC	PF$_{in}$ with AIPEC
0.1	0.8467	0.928
0.5	0.303	0.652
1.0	0.157	0.488

6. CONCLUSIONS

A new circuit for improving the input power factor has been proposed. The proposed circuit is constructed based on active elements and it is called Active Impedance Power Factor Correction (AIPFC). The operation of the AIPFC is based on a PWM technique and it has been modeled and tested using a MATLAB Program (SIMULINK). In this case, the AIPFC model has been installed in two different power electronics applications. The first application is a single phase phase-anlge controlled with resistive load. The input power factor in this application is depending on the firing angle only and it has been shown that with installing AIPFC both PF$_{in}$ and THD have been improved at any firing angle. While the second application is a single phase phase-anlge controlled with RL load. However, the input power factor in this application is depending on both the firing angle and the load angle. It has been shown that with installing AIPFC both PF$_{in}$ and THD have been also improved. In both applications more improvement of both PF$_{in}$ and THD can be achieved by increasing the compensation capacitive factor of AIPFC (modulation index of the inverter). In addition, the proposed AIPFC has been implemented and tested. The experimental results have been presented and they validate the simulation results.

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