Australian Journal of Basic and Applied Sciences, 5(3): 295-302, 2011
ISSN 1991-8178

PID Controller Adjustment using PSO for Multi Area Load Frequency Control

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Abstract: in multi area electric power systems if a large load is suddenly connected (or disconnected) to the system, or if a generating unit is suddenly disconnected by the protection equipment, there will be a long-term distortion in the power balance between that delivered by the turbines and that consumed by the loads. This imbalance is initially covered from the kinetic energy of rotating rotors of turbines, generators and motors and, as a result, the frequency in the system will change. Therefore The Load Frequency Control (LFC) problem is one of the most important subjects in the electric power system operation and control. In practical systems, the conventional PI type controllers are applied for LFC. In order to overcome the drawbacks of the conventional PI controllers, numerous techniques have been proposed in literatures. In this paper a PID type controller is considered for LFC problem. The parameters of the proposed PID controller are tuned using Particle Swarm Optimization (PSO) method. A multi area electric power system with a wide range of parametric uncertainties is given to illustrate proposed method. To show effectiveness of the proposed method, a PID type controller optimized by Genetic Algorithms (GA) is designed in order to comparison with the proposed PID controller. The simulation results visibly show the validity of PSO-PID controller in comparison with the GA-PID controller.

Key words: Multi Area Electric Power System, Load Frequency Control, Particle Swarm Optimization, Genetic Algorithms, PID Controller

INTRODUCTION

For large scale electric power systems with interconnected areas, Load Frequency Control (LFC) is important to keep the system frequency and the inter-area tie power as near to the scheduled values as possible. The input mechanical power to the generators is used to control the frequency of output electrical power and to maintain the power exchange between the areas as scheduled. A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits.

Many control strategies for Load Frequency Control in electric power systems have been proposed by researchers over the past decades. This extensive research is due to fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specifies limits. A unified tuning of PID load frequency controller for power systems via internal mode control has been proposed by Tan (2010). In this paper the tuning method is based on the two-degree-of-freedom (TDF) internal model control (IMC) design method and a PID approximation procedure. A new discrete-time sliding mode controller for load-frequency control in areas control of a power system has been presented by Vrdoljak *et al*. (2010). In this paper full-state feedback is applied for LFC not only in control areas with thermal power plants but also in control areas with hydro power plants, in spite of their non minimum phase behaviors. To enable full-state feedback, a state estimation method based on fast sampling of measured output variables has been applied. The applications of artificial neural network, genetic algorithms and optimal control to LFC have been reported by Kocaarslan *et al*. (2005); Rerkpreedapong *et al*. (2003) and Liu *et al*. (2003). An adaptive decentralized load frequency control of multi-area power systems has been presented by Zribi *et al*. (2005). Also the application of robust control methods for load frequency control problem has been presented by Shayeghi *et al*. (2007) and Taher *et al*. (2008).

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This paper deals with a design method for LFC in a multi area electric power system using a PID type controller whose parameters are tuned using PSO. In order to show effectiveness of the proposed method, this PSO-PID is compared with a PID type controller whose parameters are tuned using GA (GA-PID). Simulation results show that the PSO-PID guarantees robust performance under a wide range of operating conditions and system uncertainties.

Apart from this introductory section, this paper is structured as follows. The system under study and system modeling are presented in section 2. The design methodology is developed in section 3 and PID controller design is presented in section 4. Finally the simulation results are presented in section 5.

2. Plant model:

A four-area electric power system is considered as a test system and shown in Figure 1. The block diagram for each area of interconnected areas is shown in Figure 2 (Wood *et al*., 2003).

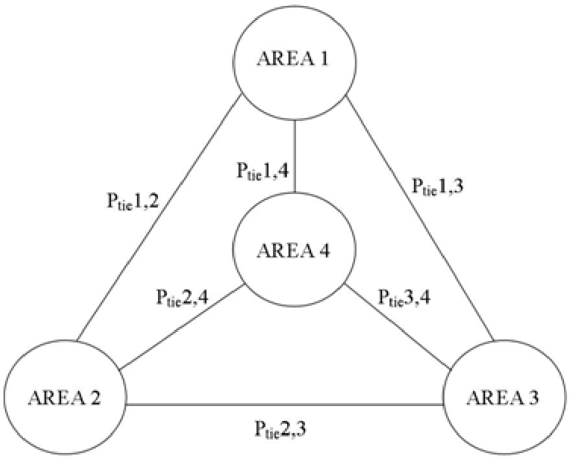

Fig. 1: Four-area electric power system with interconnections

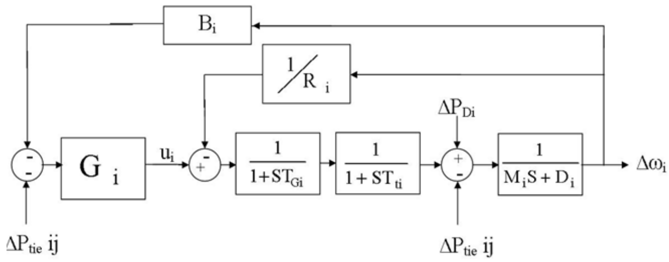

Fig. 2: Block diagram for one area of system (i^{th} area)

The parameters in Figure 2 are defined as follow:

Δ: Deviation from nominal value

M_i=2H: Constant of inertia of i^{th} area

D_i: Damping constant of i^{th} area

R_i: Gain of speed droop feedback loop of i^{th} area

T_{ti}: Turbine Time constant of i^{th} area

T_{Gi}: Governor Time constant of i^{th} area

G_i: Controller of i^{th} area

P_{Di}: Load change of i^{th} area

u_i: Reference load of i^{th} area

$B_i=(1/R_i)+D_i$: Frequency bias factor of i^{th} area

P_{tie} ij: Inter area tie power interchange from i^{th} area to j^{th} area.

Where:

i=1, 2, 3, 4 j=1, 2, 3, 4 and $i \neq j$

The inter-area tie power interchange is as (1) (Wood *et al.*, 2003).

$$\Delta P_{tie}ij=(\Delta\ \omega_i\ -\ \Delta\ \omega_j)\times(T_{ij}/S) \quad (1)$$

Where:

$T_{ij}=377\times\ (1/X_{tie}ij)$ (for a 60 Hz system)
$X_{tie}ij$: impedance of transmission line between i and j areas
The $\Delta\ P_{tie}$ ij block diagram is shown as Figure 3.

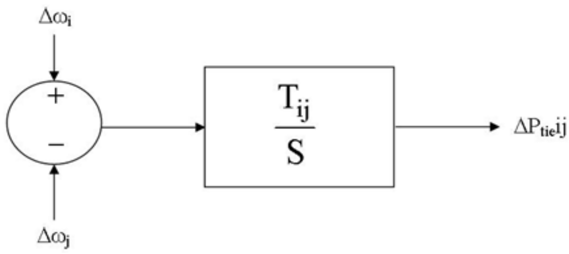

Fig. 3: Block diagram of inter area tie power ($P_{tie}ij$)

Figure 2 shows the block diagram of i^{th} area and Figure 3 shows the method of interconnection between i^{th} and j^{th} areas. The state space model of four-area interconnected power system is as (2) (Wood *et al.*, 2003).

$$\begin{cases} \dot{X} = AX + BU \\ Y = CX \end{cases} \quad (2)$$

Where:

$U=[\Delta P_{D1}\quad \Delta P_{D2}\quad \Delta P_{D3}\quad P_{D4}\quad u_1\quad u_2\quad u_3\quad u_4]$
$Y=[\Delta\omega_1\quad \Delta\omega_2\quad \Delta\omega_3\quad \Delta\omega_4\quad \Delta P_{tie}1,2\quad \Delta P_{tie}1,3\quad \Delta P_{tie}1,4\quad \Delta P_{tie}2,3\quad \Delta P_{tie}2,4\quad \Delta P_{tie}3,4]$
$X=[\Delta P_{G1}\quad \Delta P_{T1}\quad \Delta\omega_1\quad \Delta P_{G2}\quad \Delta P_{T2}\quad \Delta\omega_2\quad \Delta P_{G3}\quad \Delta P_{T3}\quad \Delta\omega_3\quad \Delta P_{G4}\quad \Delta P_{T4}\quad \Delta\omega_4$
$\Delta P_{tie}1,2\quad \Delta P_{tie}1,3\quad \Delta P_{tie}1,4\quad \Delta P_{tie}2,3\quad \Delta P_{tie}2,4\quad \Delta P_{tie}3,4]$

The matrixes A and B in (2) and the typical values of system parameters for the nominal operating condition are given in appendix.

3. Design methodology:

As mentioned before, in this paper PID controller is considered for LFC problem. The parameters of this PID controller are obtained using PSO. The PID controller structure is as (3). It contains three parameters denoted by K_P, K_I and K_D which are defined over an uncertain range and then obtained using PSO. In the next section a brief introduction about PSO is presented.

$$PID=K_P+K_I/S+K_DS \quad (3)$$

3.1. Particle swarm optimization:

PSO was formulated by Edward and Kennedy in 1995. The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO is similar to the continuous GA in that it begins with a random population matrix. Unlike the GA, PSO has no evolution operators such as crossover and mutation. The rows in the matrix are called particles (same as the GA chromosome). They contain the variable values and are not binary encoded. Each particle moves about the cost surface with a velocity. The particles update their velocities and positions based on the local and global best solutions as shown in (4) and (5) (Randy and Sue, 2004):

$$V_{m,n}^{new}=\ w\times V_{m,n}^{old}+\ \Gamma_1\times r_1\times(\ P_{m,n}^{local\ best}-P_{m,n}^{old})+\ \Gamma_2\times r_2\times(\ P_{m,n}^{global\ best}-P_{m,n}^{old}) \quad (4)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma\ V_{m,n}^{new} \tag{5}$$

Where:

$V_{m,n}$ = particle velocity
$P_{m,n}$ = particle variables
W= inertia weight
r_1, r_2 = independent uniform random numbers
$\Gamma_1 = \Gamma_2$ = learning factors
$\Delta P_{m,n}^{local\ best}$ = best local solution
$\Delta P_{m,n}^{global\ best}$ = best global solution

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of local minimizes that use derivative information, because velocity is the derivative of position. The advantages of PSO are that it is easy to implement and there are few parameters to adjust. The PSO is able to tackle tough cost functions with many local minima (Randy and Sue, 2004).

4. PID controller tuning using PSO:

In this section the parameters of the proposed PID controllers are tuned using PSO. The PID controller has three parameters denoted by K_P, K_I and K_D and for each area there is a PID controller. Therefore in four-area electric power system with four PID controllers, there are 12 parameters for tuning. These K parameters are obtained based on the PSO. In section 2, the system controllers showed in Figure 2 as G_i. Here these controllers are substituted by PID controllers showed in (3) and the optimum values of K_P, K_I and K_D are accurately computed using PSO. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (6). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$ITAE = \int_0^t t\,|\Delta\omega_1|\,dt + \int_0^t t\,|\Delta\omega_2|\,dt + \int_0^t t\,|\Delta\omega_3|\,dt + \int_0^t t\,|\Delta\omega_4|\,dt \tag{6}$$

The parameter "t" in ITAE is the simulation time. It is clear to understand that the controller with lower ITAE is better than the other controllers. To compute the optimum parameter values, a 10 % step change in ΔP_{D1} is assumed and the performance index is minimized using PSO. In order to acquire better performance, number of particle, particle size, number of iteration, Γ_1, Γ_2, and Γ are chosen as 24, 12, 40, 2, 2 and 1, respectively. Also, the inertia weight, w, is linearly decreasing from 0.9 to 0.4. It should be noted that PSO algorithm is run several times and then optimal set of parameters is selected. The optimum values of the parameters K_P, K_I and K_D are obtained using PSO and summarized in the Table 1.

Table 1: Optimum values of K_P, K_I and K_D for PSO-PID controllers

	K_P	K_I	K_D
First area PID parameters	12.0818	44.7810	1.0000
Second area PID parameters	3.3793	67.6872	2.3323
Third area PID parameters	1.0000	31.9223	1.0000
Fourth area PID parameters	13.4795	97.3224	1.0000

RESULTS AND DISCUSSIONS

In this section the proposed PSO-PID controller is applied to the system for LFC. In order to comparison and show effectiveness of the proposed method, another PID type controller optimized by genetic algorithms is designed for LFC. The optimum value of the GA-PID controllers Parameters have been obtained using genetic algorithms and summarized in the Table 2.

Table 2: Optimum values of K_P and K_I for GA-PID controllers

	K_P	K_I	K_D
First area PID parameters	3.8582	9.9389	0.3161
Second area PID parameters	5.9913	7.2451	1.7195
Third area PID parameters	5.4278	6.5321	1.8705
Fourth area PID parameters	5.3410	7.8837	2.1769

In order to study and analysis system performance under system uncertainties (controller robustness), three operating conditions are considered as follow:

i. Nominal operating condition
ii. Heavy operating condition (20% changing parameters from their typical values)
iii. Very heavy operating condition (40% changing parameters from their typical values)

In order to demonstrate the robustness performance of the proposed method, The *ITAE* is calculated following step change in the different demands (ΔP_D) at all operating conditions (Nominal, Heavy and Very heavy) and results are shown at Tables 3-4. Following step change, the PSO-PID controller has better performance than the GA-PID controller at all operating conditions.

Table 3: 5% Step increase in demand of 1st area (ΔP_{D1})

	The calculated ITAE	
	PSO-PID	GA-PID
Nominal operating condition	0.0022	0.0102
Heavy operating condition	0.0042	0.0135
Very heavy operating condition	0.0065	0.0171

Table 4: 5% Step increase in demand of 1st area (ΔP_{D1}) and 10% step increase in demand of 3rd area (ΔP_{D3})

	The calculated ITAE	
	PSO-PID	GA-PID
Nominal operating condition	0.0173	0.0188
Heavy operating condition	0.0202	0.0323
Very heavy operating condition	0.0243	0.0389

Figure 4 shows $\Delta\omega_1$ at nominal, heavy and very heavy operating conditions following 10 % step change in the demand of first area (ΔP_{D1}). It is seen that the PSO-PID controller has better performance than the other method at all operating conditions.

***Conclusions*:**

In this paper a new PSO based PID controller has been successfully proposed for Load Frequency Control problem. The proposed method was applied to a typical four-area electric power system containing system parametric uncertainties and various loads conditions. Simulation results demonstrated that the PID controllers capable to guarantee the robust stability and robust performance under a wide range of uncertainties and load conditions. Also, the simulation results showed that the PSO-PID controller is robust to change in the system parameters and it has better performance than the GA-PID type controller at all operating conditions. The PID controller is the most used controller in the industry and practical systems, therefore the paper's results can be used for the practical LFC systems.

Appendix:

The typical values of system parameters for the nominal operating condition:

1st area parameters

T_{T1}=0.035	T_{G1}=0.08	M_1=0.1667	R_1=2.4
D_1=0.0083	B_1=0.401	T_{12}=0.425	T_{13}=0.500
T_{14}= 0.400	T_{23}= 0.455	T_{24}= 0.523	T_{34}=0.600

2nd area parameters

T_{T2}=0.025	T_{G2}=0.091	M_2=0.1552	R_2=2.1
D_2=0.009	B_2=0.300	T_{12}=0.425	T_{13}=0.500
T_{14}= 0.400	T_{23}= 0.455	T_{24}= 0.523	T_{34}=0.600

3rd area parameters

T_{T3}=0.044	T_{G3}=0.072	M_3=0.178	R_3=2.9
D_3=0.0074	B_3=0.480	T_{12}=0.425	T_{13}=0.500
T_{14}= 0.400	T_{23}= 0.455	T_{24}= 0.523	T_{34}=0.600

4th area parameters

T_{T4}=0.033	T_{G4}=0.085	M_4=0.1500	R_4=1.995
D_4=0.0094	B_4=0.3908	T_{12}=0.425	T_{13}=0.500
T_{14}= 0.400	T_{23}= 0.455	T_{24}= 0.523	T_{34}=0.600

Also the matrixes A and B in (2) are as follow:

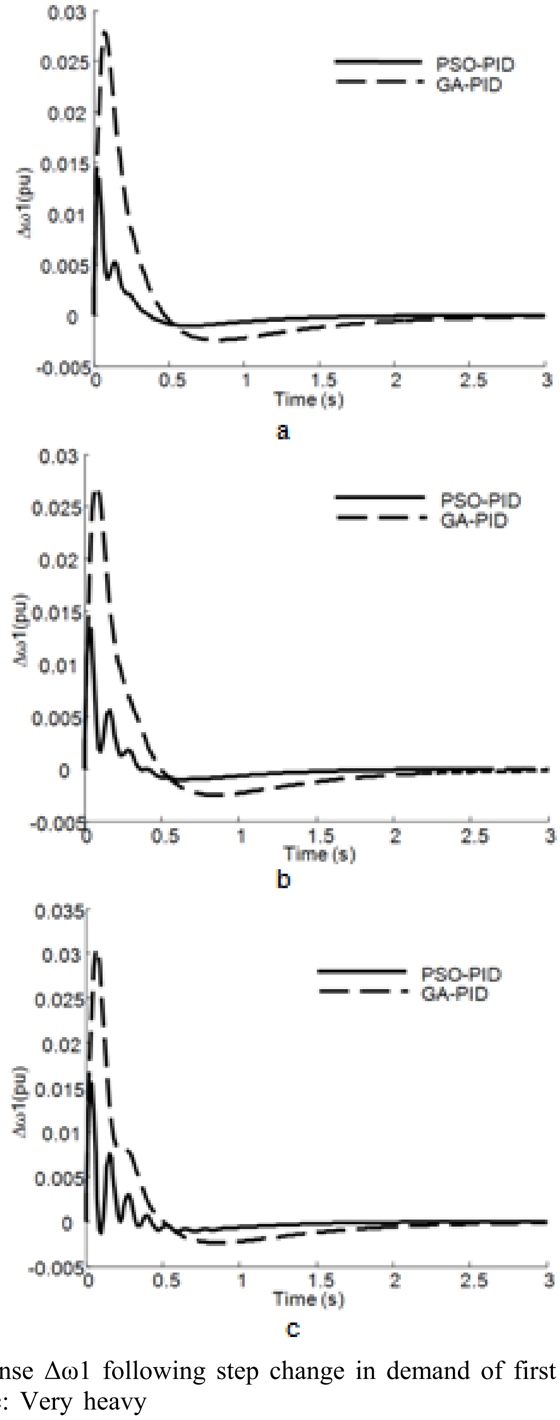

Fig. 4: Dynamic response Δω1 following step change in demand of first area (ΔP_{D1})
a: Nominal b: Heavy c: Very heavy

$$
B = \begin{bmatrix}
0 & 0 & \frac{1}{M_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_3} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_4} & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{G3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{G4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

$$
A = \begin{bmatrix}
\frac{-1}{T_{G1}} & 0 & \frac{-1}{R_1T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{1}{T_{T1}} & \frac{-1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{1}{M_1} & \frac{-D_1}{M_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{M_1} & \frac{-1}{M_1} & \frac{-1}{M_1} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{-1}{T_{G2}} & 0 & \frac{-1}{R_2T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{T_{T2}} & \frac{-1}{T_{T2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{M_2} & \frac{-D_2}{M_2} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} & 0 & 0 & \frac{-1}{M_2} & \frac{-1}{M_2} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G3}} & 0 & \frac{-1}{R_3T_{G3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{T3}} & \frac{-1}{T_{T3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_3} & \frac{-D_3}{M_3} & 0 & 0 & 0 & 0 & \frac{1}{M_3} & 0 & \frac{1}{M_3} & 0 & \frac{-1}{M_3} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G4}} & 0 & \frac{-1}{R_4T_{G4}} & 0 & 0 & 0 & 0 & 0 & 00 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{T4}} & \frac{-1}{T_{T4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_4} & \frac{-D_4}{M_4} & 0 & 0 & \frac{1}{M_4} & 0 & \frac{1}{M_4} & \frac{1}{M_4} \\
0 & 0 & T_{12} & 0 & 0 & -T_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & T_{13} & 0 & 0 & 0 & 0 & 0 & -T_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & T_{14} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_{14} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & T_{23} & 0 & 0 & -T_{23} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & T_{24} & 0 & 0 & 0 & 0 & 0 & -T_{24} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & T_{34} & 0 & 0 & -T_{34} & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

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