three-phase loads on Phase A, 30% on Phase B, and 20% on Phase C. The simulation results are listed as follows.

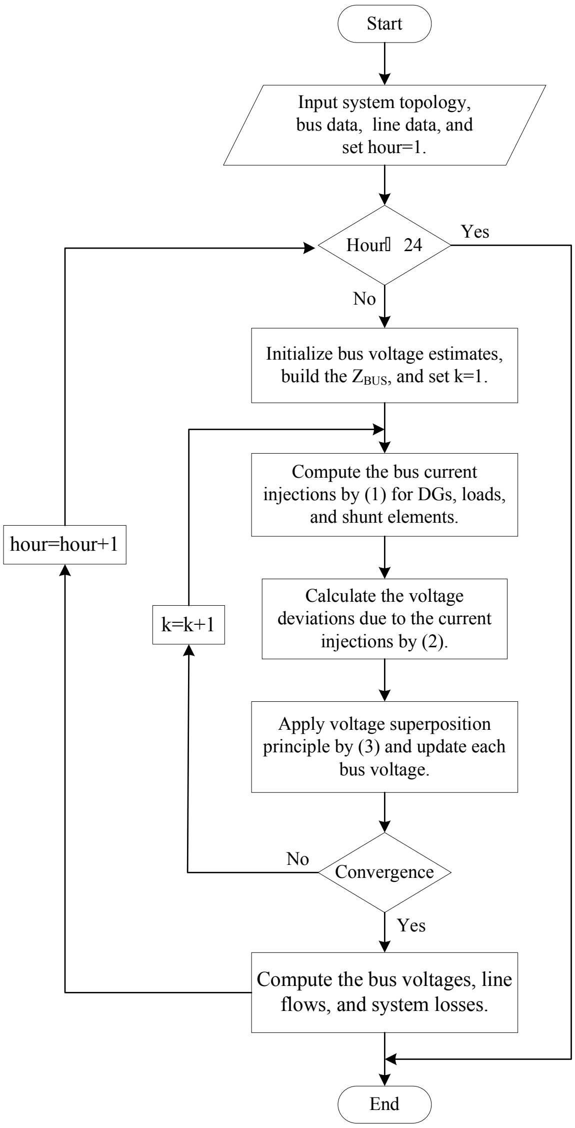

Fig. 7 A flow chart of the proposed sequential three-phase power-flow program

4.1 Distribution Transformer Loadings

After the DGs are connected to the network, the real power variations of the distribution transformer are obviously large as shown in Fig. 8; however, the reactive power variations are quite small, as shown in Fig. 9. This is primarily caused by the real power output of each DG supplying the nearby load demands, and the real power feed from the distribution transformer then being reduced. It should be noted that the real power is reversed to the primary distribution system through the distribution transformer in Phase C during the period of 0:00~06:00.

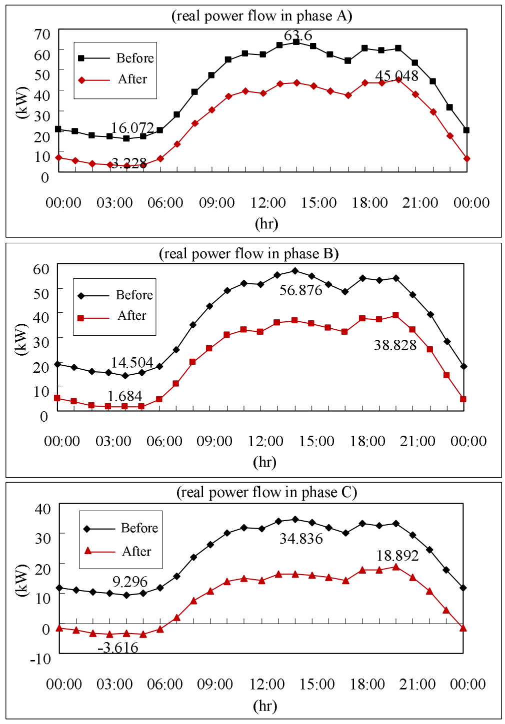

Fig. 8 Real power variations of distribution transformer before and after the DGs are connected to the network

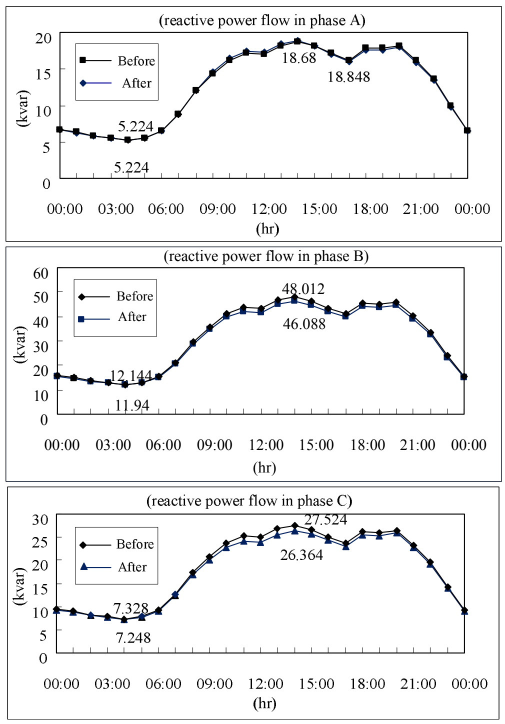

Fig. 9 Reactive power variations of distribution transformer before and after the DGs are connected to the network

4.2 Voltage Profiles

The simulation results of voltage profiles before and after the DGs are connected to the network are shown in Figures 10~15. The voltage variations at the secondary side of the distribution transformer (Bus 2) and load buses (Buses 8, 9, 10, 12, and 13) are visible. The average daily voltages at each bus are increased. Since the power feed from the DGs is large, the variations of the line currents are therefore significant. Accordingly, the more the power from the DGs, the more the line current and voltage variations rise. Additionally, the voltage drops are improved after the DGs are connected to the network. However, almost all the loads of all the buses mentioned above are larger than 3% most of the time, except for Bus 2, especially in the relatively heavier loading phase, Phase A.

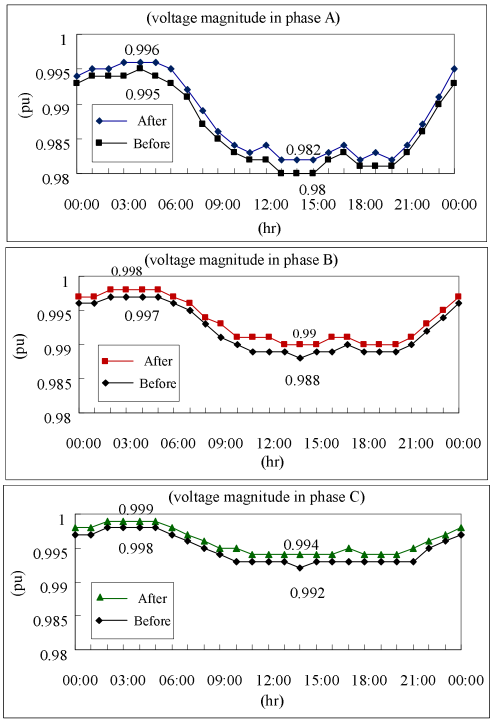

Fig.10 Voltage variations at Bus 2 before and after the DGs are connected to the network

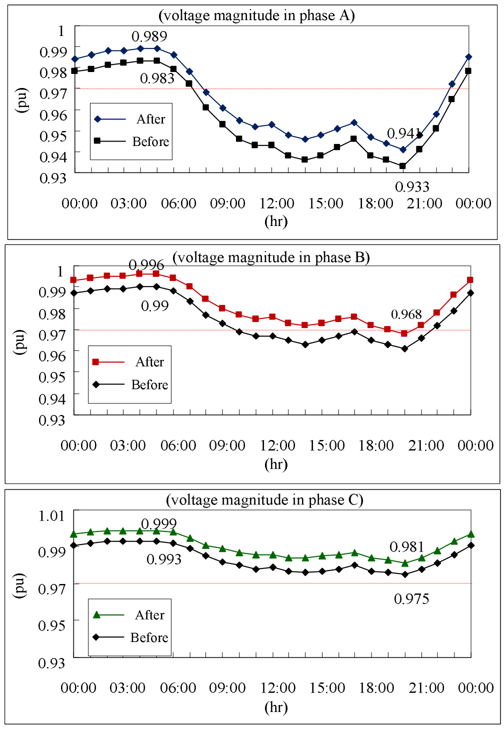

Fig. 11 Voltage variations at Bus 8 before and after the DGs are connected to the network

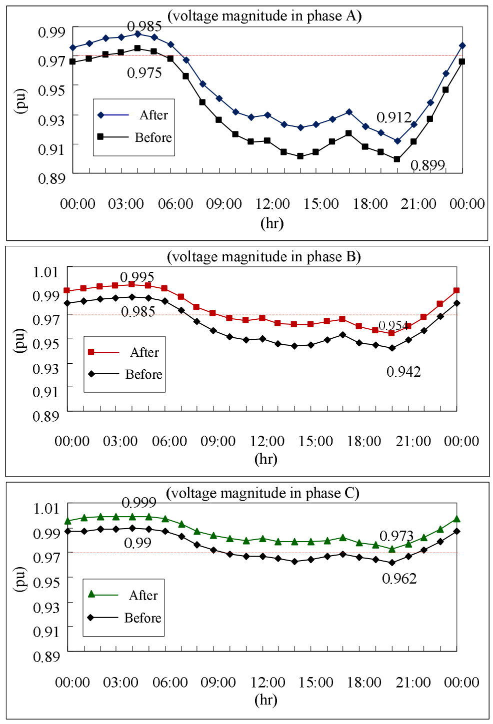

Fig. 12 Voltage variations at Bus 9 before and after the DGs are connected to the network

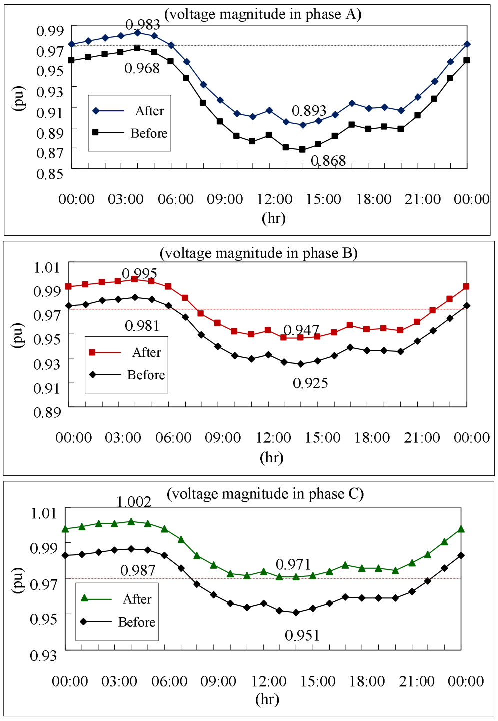

Fig. 13 Voltage variations at Bus 10 before and after the DGs are connected to the network

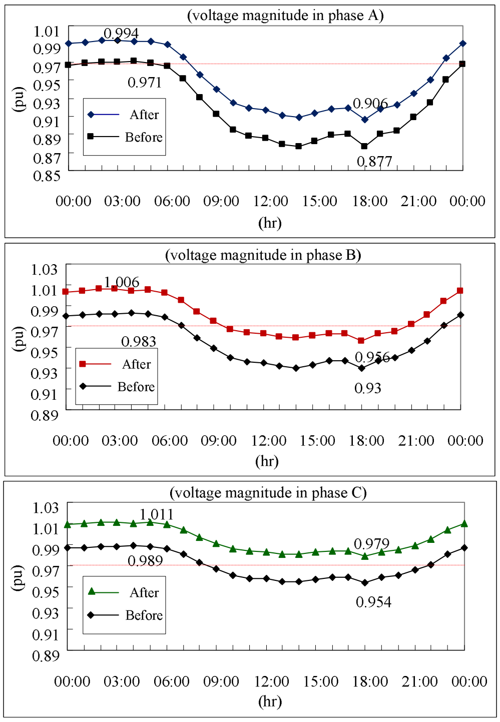

Fig. 14 Voltage variations at Bus 12 before and after the DGs are connected to the network

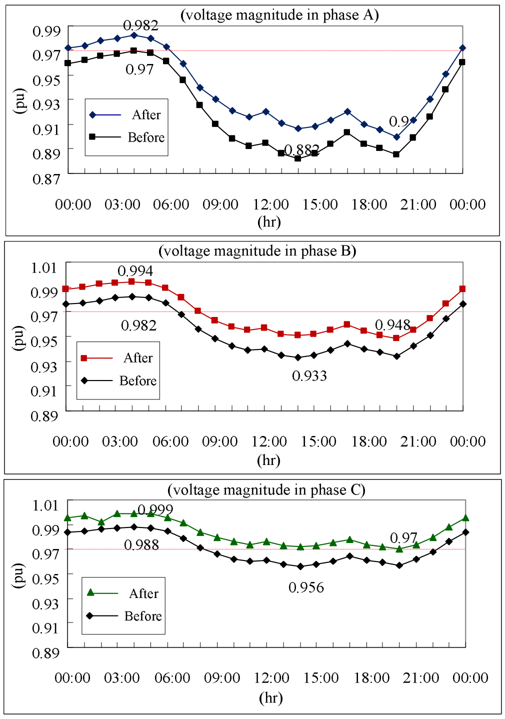

Fig. 15 Voltage variations at Bus 13 before and after the DGs are connected to the network

4.3 Line Flow Profiles

Figures 16~23 illustrate the variations of the real and reactive line flows in the line segment ahead of the DG connection point. After the DGs are interconnected, the variations of real power flow are significant. However, the variations of reactive power flow are quite small. The directions of currents in some line segments are reversed, and are directly proportional to the power from the DGs. Therefore, if the power from the DGs is increased, the conductors transfer mass power between the buses. This may lead to the conductors being overloaded, and the phenomenon should be avoided.

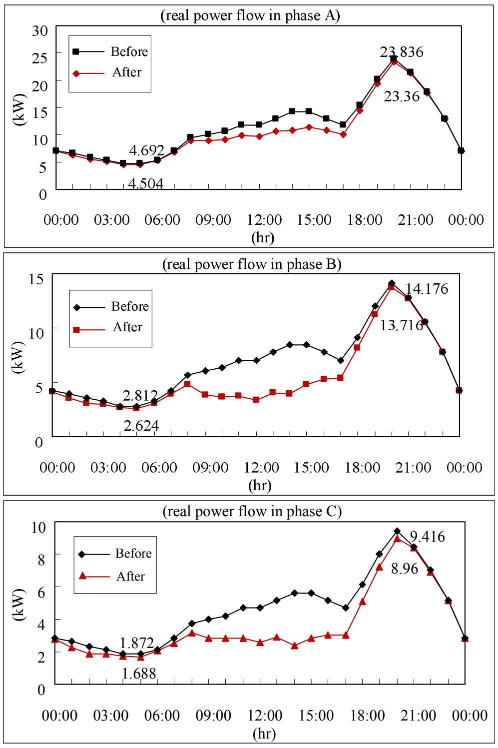

Fig. 16 Real-Power Line flow variations from Bus 5 to Bus 9 before and after the DGs are connected to the network

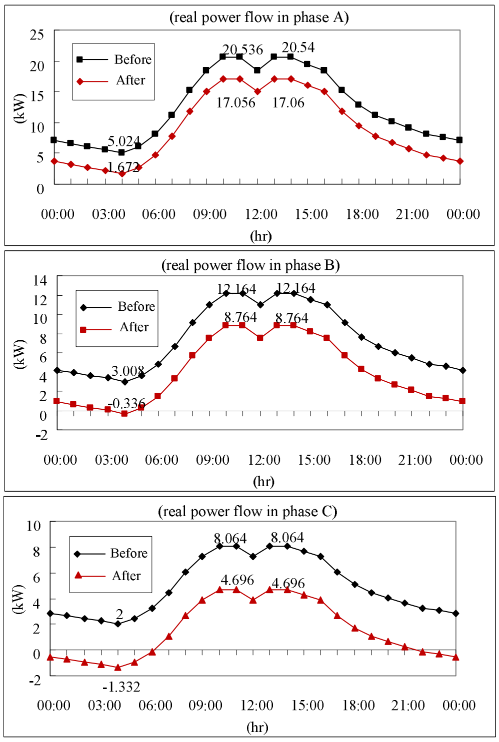

Fig. 18 Real-Power Line flow variations from Bus 7 to Bus 10 before and after the DGs are connected to the network

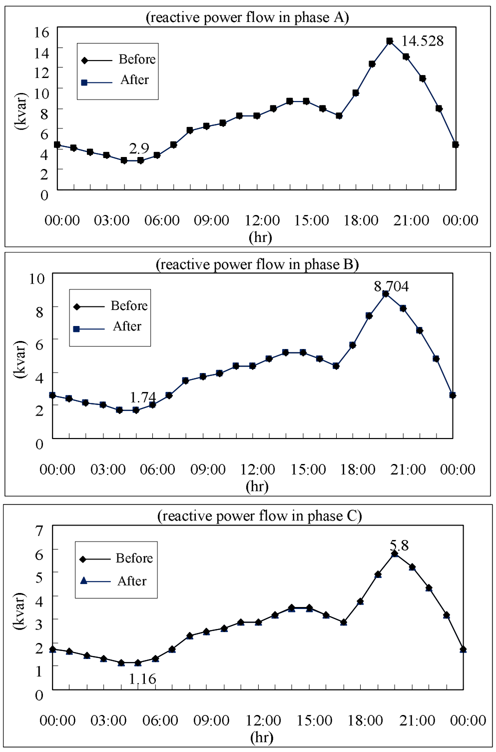

Fig. 17 Reactive-Power Line flow variations from Bus 5 to Bus 9 before and after the DGs are connected to the network

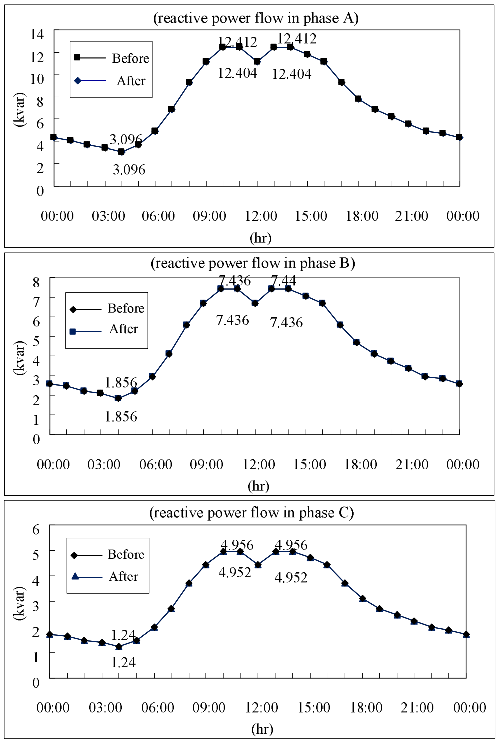

Fig. 19 Reactive-Power Line flow variations from Bus 7 to Bus 10 before and after the DGs are connected to the network

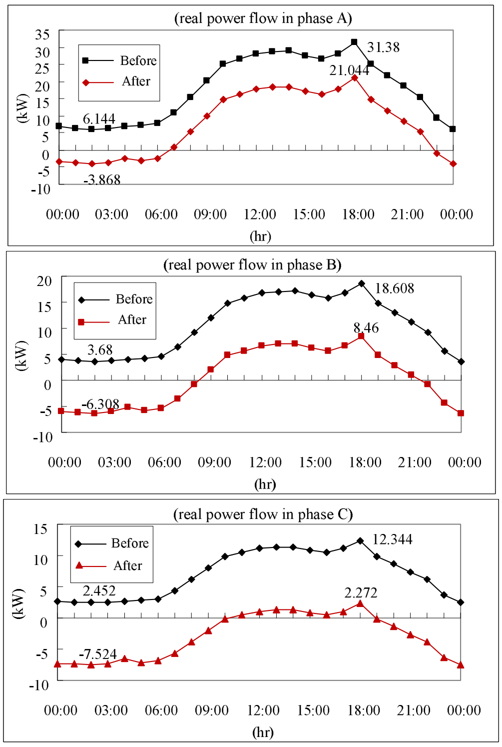

Fig. 20 Real-Power Line flow variations from Bus 11 to Bus 12 before and after the DGs are connected to the network

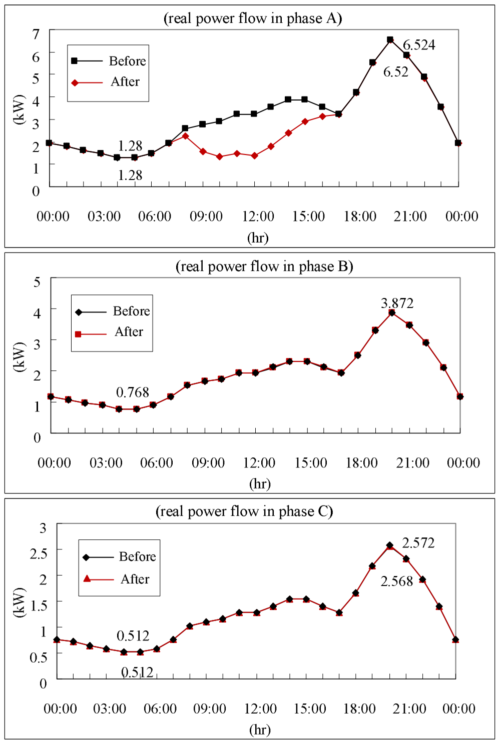

Fig. 22 Real-Power Line flow variations from Bus 6 to Bus 13 before and after the DGs are connected to the network

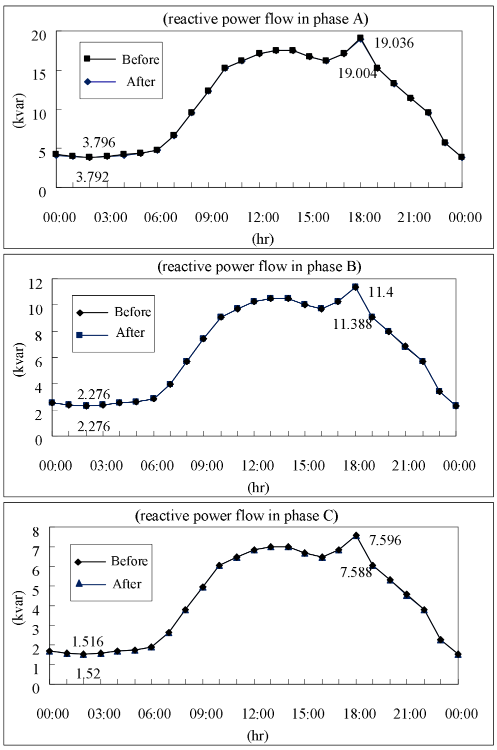

Fig. 21 Reactive-Power Line flow variations from Bus 11 to Bus 12 before and after the DGs are connected to the network

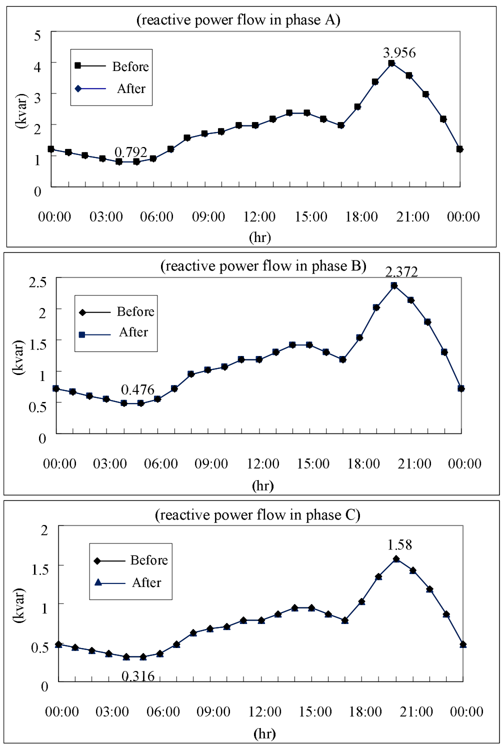

Fig. 23 Reactive-Power Line flow variations from Bus 6 to Bus 13 before and after the DGs are connected to the network

4.4 System Losses

Fig. 24 depicts the variations of the system losses before and after the DGs are connected to the network. The system losses are reduced after the DGs are connected to the network due to the DGs provide the power to meet customer's demands and reduced the power supply from the distribution transformer.

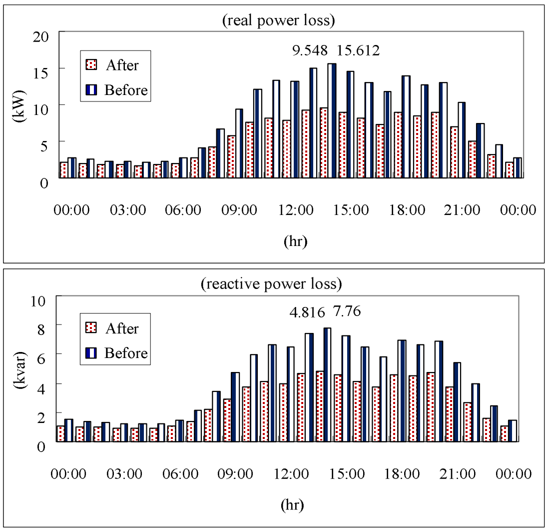

Fig. 24 System losses variations before and after the DGs are connected to the network

5 Conclusion

In this paper, based on the implicit Z_{BUS} Gauss method, the sequential three-phase power flow program is developed and tested to ensure its accuracy by commercial simulation package, CYME, and then performed the three-phase power flow analysis for a grid-connected low-voltage microgrid. The steady-state operation characteristics for a low-voltage AC microgrid with multiple DGs are then analyzed and discussed. To sum up the simulation results, after the DGs are connected to the microgrids, the average daily voltages at each bus are increased, and the tendency towards line flows and system losses is reduced. It is obvious that the DGs penetration increases the system operation efficiency and improves the voltage quality in this specific sample system.

6 Acknowledgement

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