In this paper, a novel dual-battery energy storage system (DBESS) is proposed to firmly dispatch the intermittent wind power onto the grid with a lower system operation cost. Thanks to the DBESS, a wind farm can commit to integrate constant power in each dispatching time interval. In the proposed DBESS, the battery energy storage system (BESS) that takes the charged role is active when the dispatch power is lower than the wind power, and another is enabled if the dispatch power is higher than the wind power. These roles of the BESSs switch when one BESS is either fully charged or deeply discharged. To extend the BESS lifetime, the dispatch power is optimized to ensure both BESSs are operating under full charge-discharge cycles, so the system's operating cost is reduced significantly by using the proposed DBESS. In addition, short-term power dispatch control is considered to deal with wind power forecasting errors. In order to evaluate the proposed optimized system, we performed several numerical studies using a 3-MW wind turbine generator with real wind power data. Moreover, a wind-battery power test bed is implemented in the laboratory to validate the feasibility of the proposed DBESS.