

**ANALYSIS OF OPTIONS TO LIMIT OCCURRENCE
AND DURATION OF UNDER FREQUENCY LOAD
SHEDDING IN SMALL, RENEWABLE-DOMINANT
POWER SYSTEMS: THE CASE OF SRI LANKA**

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Degree of Master of Science

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University of Moratuwa

Sri Lanka

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree
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DECLARATION OF THE CANDIDATE & SUPERVISORS

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ABSTRACT

The power system Sri Lanka is an islanded power system of a relatively small size. Other than the coal power plants, combined cycle plants and gas turbines, a significant portion of electricity requirement is supplied by large hydro, mini hydro and other non-conventional renewable energy power plants. Accordingly, the power system of Sri Lanka can be identified as a low-inertia power system.

CEB, the power transmission operator of Sri Lanka, adheres to N-1 reliability in the transmission network. They are not expected to keep N-1 reliability in generation according to the current practice. It means that the internationally practiced power system reliability levels do not exist in the power system Sri Lanka.

Even before Non-Conventional Renewable Energy (NCRE) additions, the power system was largely dependent on under-frequency load shedding (UFLS) after large generator disconnection. Introducing NCRE to the power system has worsened the situation further.

The aim of the study was to identify the behavior of the power system of Sri Lanka during and after generation disconnection and study possible methods to improve the power system performance after generation disconnection event. The impact of battery energy storage systems on frequency response was studied for the power system of Sri Lanka. A cost analysis on battery energy storage system was performed. Increase in costs was also calculated if an internationally practiced level of spinning reserve is maintained in the power system Sri Lanka. Suggestions to improve the performance of the system are included in the thesis, based on the findings of the research.

Key word: BESS, CBEST, spinning reserve, UFLS, PSS/E

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LIST OF ABBREVIATIONS

| Abbreviation | Description |
|--------------|--|
| ac | Alternating current |
| AEMO | Australian Energy Market Operator Limited |
| BESS | Battery Energy Storage System |
| BOP | Balance of Plant |
| C&C | Construction and Commissioning |
| CAISO | California Independent System Operator |
| CC | Combined Cycle |
| CCP | Combined Cycle plant |
| CEB | Ceylon Electricity Board |
| dc | Direct Current |
| EIA | Energy Information Administration |
| EMS | Energy Management System |
| ENS | Energy Not Served |
| EPC | Engineering, Procurement and Construction |
| EPRI | Electric Power Research Institute |
| FACTS | Flexible Alternating Current Transmission System |
| GT | Gas turbine |
| GWh | Giga watthour |
| IEA | International Energy Agency |
| IRENA | International Renewable Energy Agency |
| KPS | Kelanitissa Power Station |
| kWh | Kilo watthour |
| LCOS | Levelized Cost of Storage |
| Li-ion | Lithium-ion |
| LNG | Liquified Natural Gas |
| LVPS | Lakvijaya Power Station |
| MCM | Million Cubic Meters |
| Mvar | Mega voltampere reactive |

| | |
|---------|---|
| MW | Mega watt |
| MWh | Mega watthour |
| NCRE | Non-Conventional Renewable Energy |
| NIPSCO | Northern Indiana Public Service Company |
| NREL | National Renewable Energy Laboratory |
| O&M | Operation and Maintenance |
| ORE | Other Renewable Energy |
| PCS | Power Conversion System |
| PNNL | Pacific Northwest National Laboratory |
| PSE | Battery Storage Information |
| PSS/E | Power System Simulator for Engineers |
| PV | Photovoltaic |
| PYSERDA | New York State Energy Research and Development Authority |
| ROCOF | Rate of Change of Frequency |
| UFLS | Under Frequency Load Shedding |
| USA | United States of America |
| WCP | West Coast Power |