Memorial University of Newfoundland
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Efficient water-based electricity strategies to reduce the number of switching operations in a smart grid

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Presentation Outline

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  - Evaluation of The Proposed Energy Strategy
  - Energy Transaction Analysis of the Water-power System
  - The Simulation of the Uncertainty Model

- **Conclusion**
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Background

- **Industrialization Process in the 20th Century**

- **Importance of Transmission Lines**
- To reduce power loss percentage, it is necessary to transmit electricity at high voltages. The higher the voltage, the lower the current, which reduces the size of the required cable and the amount of energy lost.
- **Transmission Line Overload**
- For various reasons such as line outages, generator outages, and changes in power exchange contracts, parts of the transmission network may face overloads. For example, with the outage of one of the network lines, several power transmission paths from production sites to consumption sites
- **Transmission Congestion**
- In a competitive market, consumers always prefer to purchase their required power from cheaper production units. The concentration of more efficient and cheaper units in a specific area of the network leads to an increase in the power density transmitted through the lines and transmission equipment of that area

Background

- **Security-Constrained Unit Commitment (SCUC) problem.**
  - This problem is one of the essential tools for system operators to create an operational and real-time performance plan. Internalizing the transmission network and security constraints (e.g., N-1 criterion) can lead to various decisions in production dispatching.
- **Transmission Switching**
  - Fossil fuel-based power generation is expensive, especially in the long term.

- **Electricity Shortages and Unreliable Power Supply**
  - This problem is used to reduce problem probability
  - One of the main challenges of this issue is the high number of switching, which reduces the lifespan of CBs, causes CB failures, and decreases system stability.
  - In addition to improving operational costs, this research proposes a method to reduce the number of transmission switching in TS.
  - Congestion management here is used to reduce the number of switching and improve system reliability because it prevents lines from operating at their maximum limit and avoids additional switching.

Literature Review

MEMORIAL UNIVERSITY

Reviewed Paper	Description
Sheikh Mohammadi (2018)	Bi-level optimization model for coordination between transmission and distribution systems interacting with local energy markets
Chabanloo (2018)	Examination of a comprehensive coordination of the resilience of radial distribution networks in the presence of distributed generation sources using fault current limiters.
Saviozzi (2019)	This research designed and implemented two advanced functions in a real DMS: load forecasting and load modeling.
Das (2019)	This research examined security-constrained AC transmission network expansion planning (TNEP) programs.
Gan (2019)	In this study, the Benders decomposition algorithm is introduced to divide the joint planning problem into a main problem and two sub-problems.
Sahoo (2012)	This research investigated multi-objective planning of electrical distribution systems including sectional switches and tie lines using particle swarm optimization.

Literature Review

Reviewed Paper	Description
Lee (2016)	This paper addresses the challenges of the transmission network by developing a real-time contingency analysis (RTCA) tool based on corrective AC transmission switching (CTS) that can manage large-scale systems in a reasonable time.
Chen (2022)	In this paper, a model-based Security-Constrained Unit Commitment (SCUC) for the electricity market is presented.
Wu (2016)	This research analyzed Security-Constrained Unit Commitment (SCUC) with uncertainties.
Rahmani (2020)	This research introduced a stochastic, two-stage, reliability-focused Security Constrained Unit Commitment (SCUC) in the context of a smart grid.
Bahrami (2017)	This paper put forward a model-based SCUC for AC-DC grids with generation and load uncertainty
He (2021)	This research examined how to enhance power grid flexibility using battery energy storage transportation (BEST) and transmission switching (TS).

Research Objectives

- **Proposing a coefficient congestion-based water-power energy strategy to amend the transmission switching within the power systems**

- **Modeling linking energy management for multi-energy demands based on the water-power energy system to be effective for improving the line congestion during the grid-connected mode.**

- **Representing the UT-based uncertainty strategy to model the highrisk multi-energy demands within the based electrical grid connected to the water-power system**

Problem Description

➢ **The water-power demand supplement system**

Problem Formulation

- **Research Purpose**

- SCUC model that incorporates Transmission Switching (TS) with Dynamic Thermal Line Rating (DTLR) serving as security constraints

- **Main Objective Function**

$$Min\ Z^{down} = \sum_{t}\sum_{g} C(P_{g,t}) + SU_{g,t} + SD_{g,t} + C\Delta r^{S}{}_{g,t} \qquad (1)$$

g: generator
t: time
SU: generator start up cost
SD: generator shot down cost
Δr: scenario

Problem Formulation

➢ **Constraints**

- Active and Reactive Powers

$$P_g^{min} u_{g,t} uc_g^S \leq P_{g,t} + \Delta r_{g,t}^S \leq P_g^{max} u_{g,t} uc_g^S \quad (2)$$

$$Q_g^{min} u_{g,t} uc_g^S \leq Q_{g,t} + \Delta r_{g,t}^S \leq Q_g^{max} u_{g,t} uc_g^S \quad (3)$$

uc: contingency state

Problem Formulation

➢ Constraints

- Binary variables

$$v_{g,t} - w_{g,t} = u_{g,t} - u_{g,t-1} \qquad (4)$$

$$\sum_{t'=t-UT_g+1}^{t} v_{g,t'} \leq u_{g,t} \qquad (5) \qquad\qquad \sum_{t'=t-DT_g+1}^{t} w_{g,t'} \leq 1 - u_{g,t} \qquad (6)$$

v: entry of generator
w; exit of generator

Problem Formulation

- **Constraints**

- Ramp up/down

$$P_{g,t} - P_{g,t-1} \leq R_g^{+} u_{g,t-1} + R_g^{SU} v_{g,t} \qquad (7)$$

$$P_{g,t} - P_{g,t-1} \leq R_g^{+} u_{g,t-1} + R_g^{SU} v_{g,t} \qquad (8)$$

- Generator's reserve capacity

$$-SR_g^{+} \leq \Delta r_{g,t}^{S} \leq SR_g^{+} \qquad (9)$$

R_g^{+}, SR_g^{+}: maximum ramp up/down rate [MW]

Problem Formulation

- **Constraints**

- Active and Reactive Power Balance

$$\sum_{\forall g(b)} \left(P_{g,t} + \Delta r_{g,t}^{S}\right) + P_t^{EH} - \sum_{\forall k(b,m)} \left(P_{k,t}^{S} + 0.5PL_{k,t}^{S}\right) = PD_{b,t}^{S} \qquad (10)$$

$$\sum_{\forall g(b)} Q_{g,t}^{S} + \sum_{\forall k(b,m)} \left(Q_{k,t}^{S} - 0.5QL_{k,t}^{S}\right) = QD_{b,t} \qquad (11)$$

Problem Formulation

➢ **Constraints**

- Operation of Transmission Switching

$$P^S_{b,m,k,t} - M\left(1 - z_{k,t} zc^S_k\right) \le P^S_{k,t} \le P^S_{b,m,k,t} + M\left(1 - z_{k,t} zc^S_k\right) \quad (12)$$

$$Q^S_{b,m,k,t} - M\left(1 - z_{k,t} zc^S_k\right) \le Q^S_{k,t} \le Q^S_{b,m,k,t} + M\left(1 - z_{k,t} zc^S_k\right) \quad (13)$$

zc^S_k : contingency state of line k
$z_{k,t}$: connection and disconnection line
$P^S_{b,m,k,t}$: power flow between line b and bus m

Problem Formulation

- **Constraints**

- Limits on the Lines Power Flow

$$-P_k^{max}.z_{k,t}.zc_k^S \leq P_{k,t}^S \leq P_k^{max}.z_{k,t}.zc_k^s \qquad (14)$$

$$-S_k^{max}.z_{k,t}.zc_k^S \leq Q_{k,t}^S \leq S_k^{max}.z_{k,t}.zc_k^s \qquad (15)$$

Problem Formulation

- **Constraints**

- Active & Reactive Power Line Loss

$$g_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^{S}(l) - M(1 - z_{k,t} zc_k^S) \le PL_{k,t}^S \le g_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^{S}(l) + M\left(1 - z_{k,t} zc_k^S\right) \qquad (16)$$

$$0 \le PL_{k,t}^S \le z_{k,t}.zc_k^S.g_k(\delta_k^{max})^2 \qquad (17) \quad , \quad 0 \le QL_{k,t}^S \le -z_{k,t}.zc_k^S.g_k(\delta_k^{max})^2 \qquad (18)$$

$$-b_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^{S}(l) - M\left(1 - z_{k,t} zc_k^S\right) \le QL_{k,t}^S \le -b_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^{S}(l) + M\left(1 - z_{k,t} zc_k^S\right) \qquad (19)$$

Problem Formulation

- **Constraints**

- Limitations on the Magnitude and Angle of Bus Voltage

$$\delta_k^{min} \leq \delta_{k,t}^{S} \leq \delta_k^{max} \qquad (20)$$

$$\Delta V^{min} \leq \Delta V_{b,t}^{S} \leq \Delta V^{max} \qquad (21)$$

$$-\Delta SP_k^{max} - M\left(z_{k,t-1} - z_{k,t} + 1\right)zc_k^S \leq \delta_{k,t}^{S} \leq \Delta SP_k^{max} + M\left(z_{k,t-1} - z_{k,t} + 1\right)zc_k^S \qquad (22)$$

$$\delta_{k,t}^{+S} - \delta_{k,t}^{-S} = \delta_{k,t}^{S} \qquad (23)$$

$$\Delta V_{b,t}^{+S} - \Delta V_{b,t}^{-S} = \Delta V_{b,t}^{S} \qquad (24)$$

Problem Formulation

- **Constraints**

- Congestion Management

$$\sum_{g} \left(GS_g^k \Delta P_g \right) + P_k^0 \leq P_k^{max} \qquad (25)$$

$$\sum_{g} \Delta P_g = 0 \qquad (26)$$

$$GS_g^k = \frac{\Delta P_k}{\Delta P_g} \qquad (27) \quad , \quad GS_g^k = \frac{\partial P_k}{\partial \delta_b} \cdot \frac{\partial \delta_b}{\partial P_g} + \frac{\partial P_k}{\partial \delta_m} \cdot \frac{\partial \delta_m}{\partial P_g} \qquad (28)$$

Problem Formulation

- **The mathematical definition of the introduced water-power system**

- **Objective Function**

$$C^{hub} = \sum_{t \in \Omega^T} \left(P_t^{EH} \times R_{EH} + Pa_t^{bat} \times Ra_{bat} + Pc_t^{CH} \times Rc_{CHP} + Pb_t^{Boi} \times Rb_{Boi} + Wa_t^{Grid} \times Ra_{water} \right) \quad (29)$$

Problem Formulation

- **Water-power System Constraints**

- Electrical:

$$P_t^L + P_t^{Des} = \delta_e^T P_t^{EH} + P_t^{FU} + \delta_{ch} Pc_t^{CH} + Pa_t^{bat}, \forall t \in \Omega^T \quad (30)$$

$$\underline{Ea}^{bat} \le Ea_t^{bat} \le \overline{Ea}^{bat}, \forall t \in \Omega^T \quad (31) \quad , \quad Ea_t^{bat} = \left(1 - \varphi_e^{loss}\right) Ea_{t-1}^{bat} + Pa_t^{bat}, \forall t \in \Omega^T \quad (32)$$

$$\frac{1}{\delta_e} \underline{Pa}^{bat} \le Pa_t^{bat} \le \frac{1}{\delta_e} \overline{Pa}^{bat}, \forall t \in \Omega^T \quad (33) \quad , \quad \underline{P_t}^{EH} \le P_t^{EH} \le \overline{P}_t^{EH}, \forall t \in \Omega^T \quad (34)$$

$$P_t^{FU} = P_t^{FL} + P_t^{FB}, \forall t \in \Omega^T \quad (35) \quad , \quad P_{FC}^{min} \le P_t^{FL} + P_t^{FB} \le P_{FC}^{max}, \forall t \in \Omega^T \quad (36)$$

$$0 \le nH_2^t \le nH_2^{max}, \forall t \in \Omega^T \quad (37) \quad , \quad nH_2^t = (P_t^{FL} + P_t^{FB}) \times \frac{3.6^{MJ}/_{kWh}}{119.96^{MJ}/_{Kg}}, \forall t \in \Omega^T \quad (38)$$

Problem Formulation

- **Water-power System Constraints**

- Heat:

$$P_t^H = \delta_{ch} Pc_t^{CH} + \delta_{boi} Pb_t^{Boi}, \forall t \in \Omega^T \qquad (39)$$

$$P_t^G = Pc_t^{CH} + Pb_t^{Boi}, \forall t \in \Omega^T \qquad (40)$$

$$\delta_e^{Trans} P_t^{EH} \leq Cap^T, \forall t \in \Omega^T \qquad (41)$$

$$\delta_{ch} Pc_t^{CH} \leq Cap^{CH}, \forall t \in \Omega^T \qquad (42)$$

$$\delta_{boi} Pb_t^{boi} \leq Cap^{boi}, \forall t \in \Omega^T \qquad (43)$$

Problem Formulation

- **Water-power System Constraints**

- Water:

$$S_t^T = S_{t-1}^T + W_t^{Grid} + W_t^{sea} - W_t^l, \forall t \in \Omega^T \quad (44)$$

$$\underline{S}^T \leq S_t^T \leq \overline{S}^T, \forall t \in \Omega^T \quad (45)$$

$$\underline{W}^{sea}.I_t^{DT} \leq W_t^{sea} \leq \overline{W}^{sea}.I_t^{DT}, \forall t \in \Omega^T \quad (46)$$

$$P_t^{Des} = W_t^{sea}.CF^{Des-W} \quad (47)$$

Problem Formulation

- **Modeling of Uncertainty**

- The probability of equipment failure
- The correlation probability among these failures

- **UT uncertainty model**

- Failure of all lines
- Failure of generation units
- Water demands
- Thermal demands
- Electrical load demands

Problem Formulation

- **UT Approach for Uncertainty**

- Step 1: Compute the points by:

$$X^0 = z \qquad (48)$$

$$X^k = z + \left(\sqrt{\frac{p}{1 - W^0} Y_{aa}}\right)_k, k = 1, 2, \dots, p \qquad (49)$$

$$X^{k+c} = z + \left(\sqrt{\frac{p}{1 - W^0} Y_{aa}}\right)_k, k = 1, 2, \dots, p \qquad (50)$$

Y_{aa} is the covariance matrix by $\overline{R} = z$

Problem Formulation

- **UT Approach for Uncertainty**

- Step 2: the points' weights are computed using:

$$W^k = \frac{1 - W^0}{2p} \quad , \qquad k = 1, 2, \dots, 2p \qquad (51)$$

- Step 3: Ultimately, the outputs can be obtained by using $\hat{f}(X^k)$ as follows:

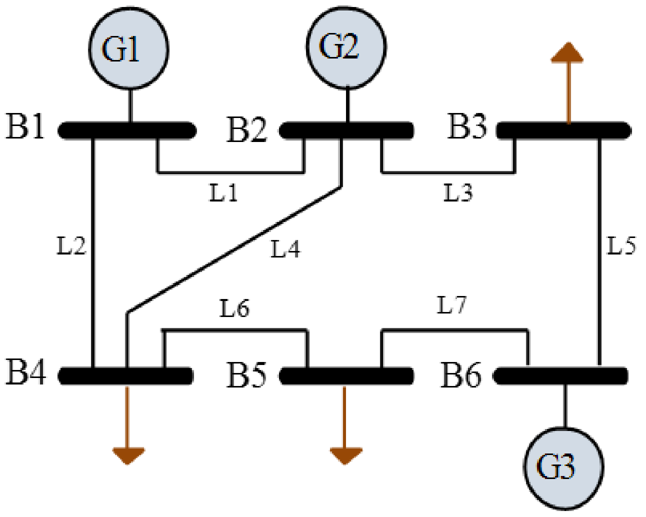
$$\overline{T} = \sum_{k=0}^{2p} W^k T^k \qquad (52)$$

$$C_{TT} = \sum_{k=1}^{2p} W^k \left(T^k - \overline{T}\right)\left(T^k - \overline{T}\right)^R \qquad (53)$$

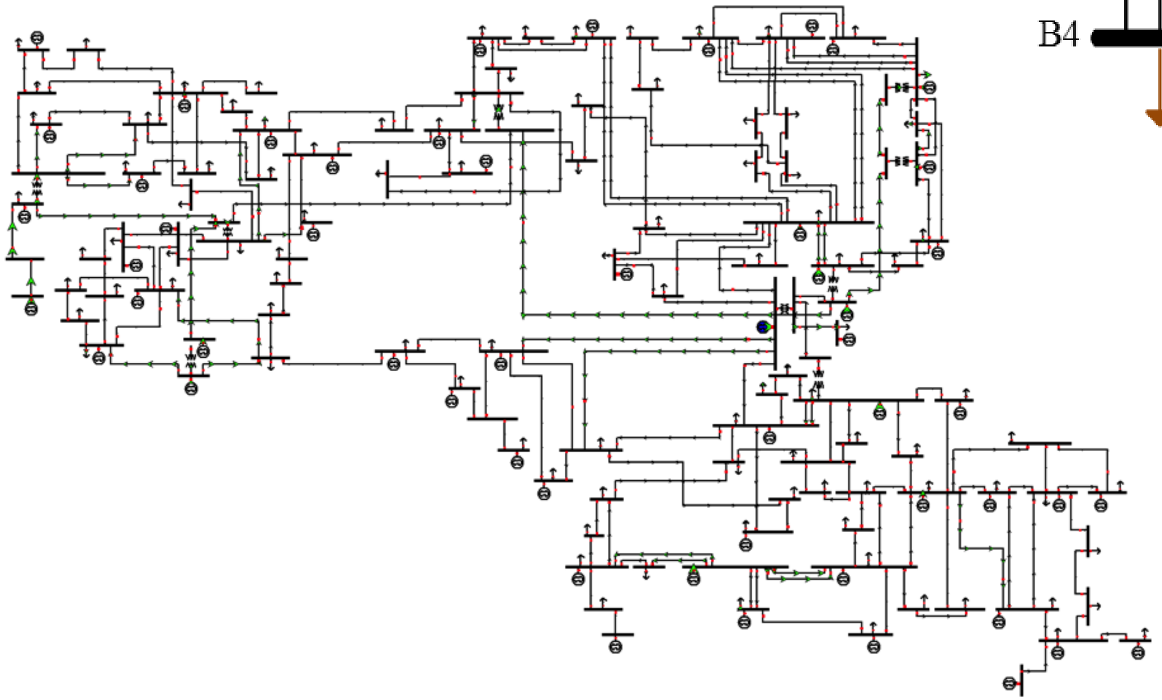
Case Study

➢ **System Models**

- IEEE standard 6-bus system



- IEEE 118-Bus System



Case Study

- **Detailed information**

- IEEE standard 6-bus - Generators data

	G1	G2	G3
price of energy bid ($/MWh)	20	23	35
Ramp up/down rate (MW/h)	55	50	20
cost of start-up ($)	100	100	100
P_{max} (MW)	220	200	50
P_{min} (MW)	100	10	10
Q_{max} (MW)	200	70	50
Q_{min} (MW)	-80	-40	-40
Minimum up time (h)	4	3	1
Minimum down time (h)	4	2	1

Case Study

- **Detailed information**

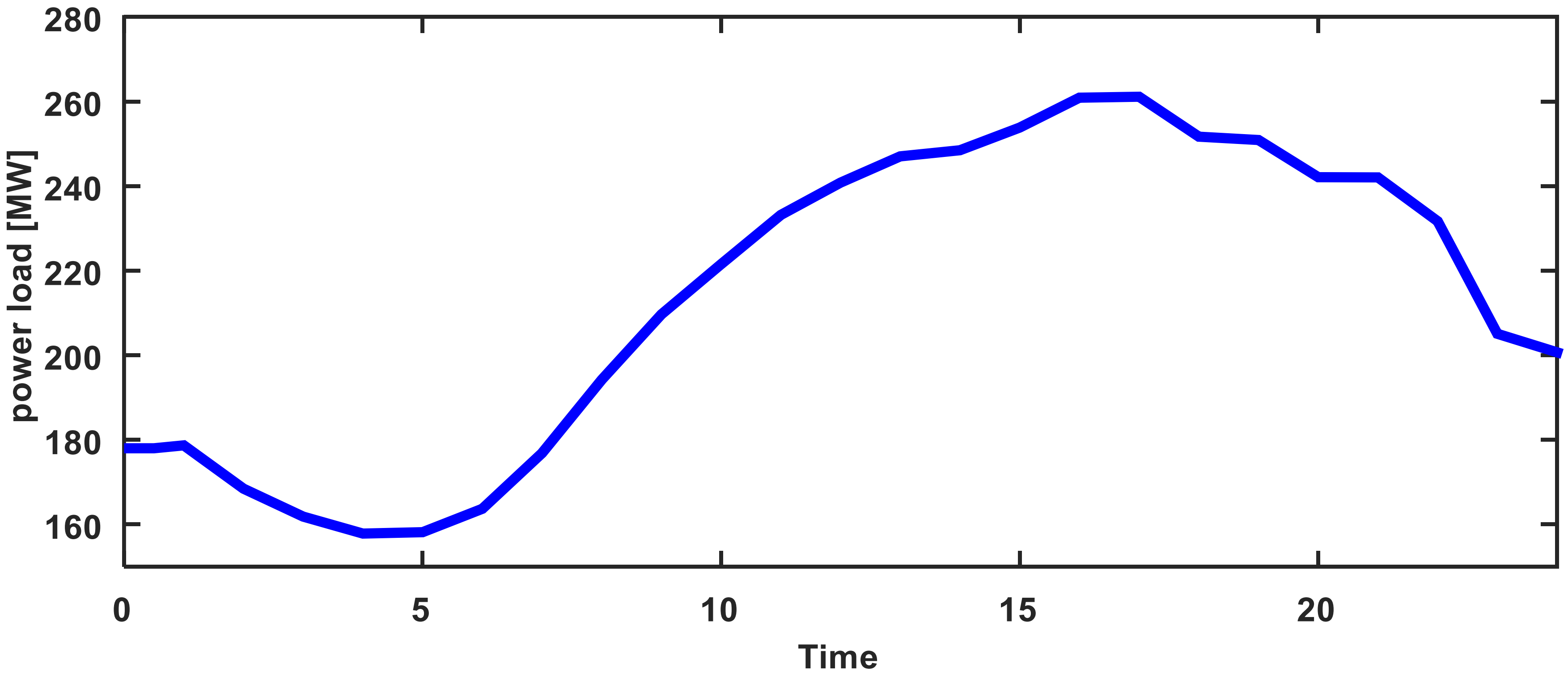
IEEE standard 6-bus – Transmission Lines Data

Line number	From bus	To bus	X_l (pu)	R_l (pu)	Flow limit (MW)
L1	1	2	0.17	0.005	150
L2	1	4	0.258	0.003	150
L3	2	3	0.037	0.022	150
L4	2	4	0.197	0.007	150
L5	3	5	0.018	0.005	150
L6	4	5	0.037	0.002	37
L7	5	6	0.14	0.002	150

Case Study

➢ **Detailed information**

- Load of IEEE 6-bus test grid – Load curve over 24 h



Case Study

- **Detailed information**

- Load of 6-bus IEEE test grid – Computation Details

Platform	GAMS
Solver	CPLEX
Processor	3.4 GHz
RAM	32 GB

Evaluation of The Proposed Energy Strategy

- The congestion management was performed during 24-hour period to demonstrate its effects on the TS power flow

Evaluation of The Proposed Energy Strategy

- **Scenarios according to the high-crucial lines and generators for two 6-bus and 118-bus power grids**

Scenario #	Outage of generator #	switching of line #-#	SLR method	Proposed method	Base system
1	2	2-4	*		6 bus
2	2	4-5	*		6 bus
3	2	2-4		*	6 bus
4	2	4-5		*	6 bus
5	13	30-34	*		118 bus
6	13	67-78	*		118 bus
7	13	90-92	*		118 bus
8	13	30-34		*	118 bus
9	13	67-78		*	118 bus
10	13	90-92		*	118 bus

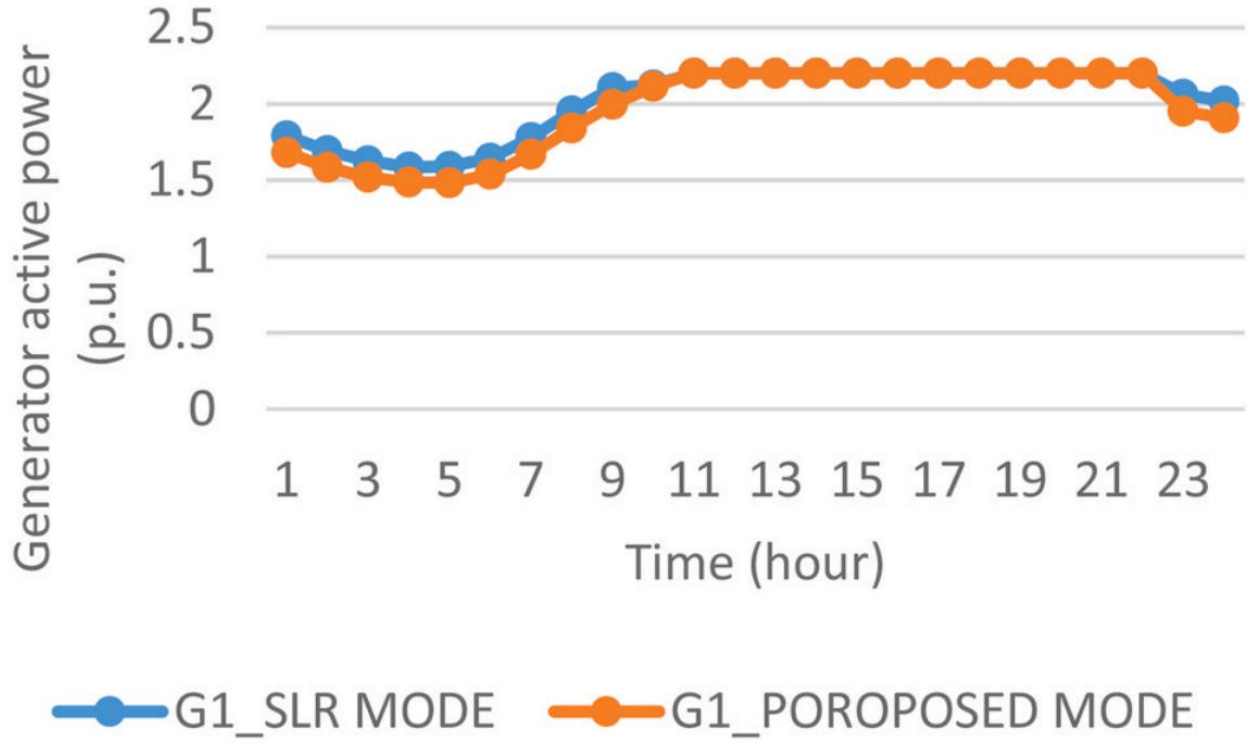
Evaluation of The Proposed Energy Strategy

- Comparison of TS implementation in Static Line Rating (SLR) mode and introduced model with various scenarios

		Case #	Line#-#	# of switching	Cost ($)
6 bus system (generator 2 is out)	SLR mode	I	2-4	9	3.108×10^5
		II	4-5	14	
	Proposed model	III	2-4	2	2.3935×10^5
		IV	4-5	3	
118 bus system (generator 13 is out)	SLR mode	V	30-34	11	1.091×10^6
		VI	67-78	10	
		VII	90-92	8	
	Proposed model	VIII	30-34	6	1.0075×10^6
		IX	67-78	3	
		X	90-92	4	

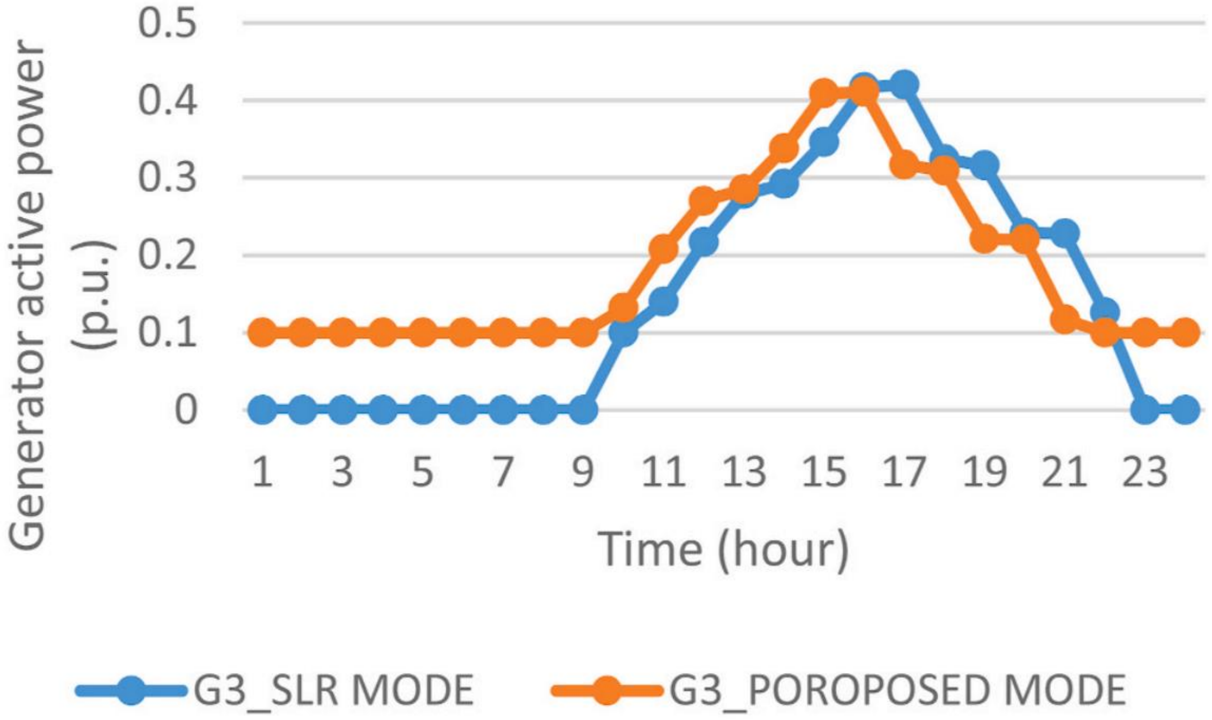
Evaluation of The Proposed Energy Strategy

- Generation schedule of generator number 1 for SLR mode and proposed model



Evaluation of The Proposed Energy Strategy

- Generation schedule of generator number 3 for SLR mode and proposed model



Evaluation of The Proposed Energy Strategy

- Computation result for SLR model for 6-bus system

SLR Model												
Time	1	2	3	4	5	6	7	8	9	10	11	12
$\Delta P_{g=1}$	0	0	0	0	0	0	0	0	0	0.076	0	0
Time	13	14	15	16	17	18	19	20	21	22	23	24
$\Delta P_{g=1}$	0	0	0	0	0	0	0	0	0	0.019	0	0
Time	1	2	3	4	5	6	7	8	9	10	11	12
$\Delta P_{g=3}$	0	0	0	0	0	0	0	0	0	0.024	0.141	0.218
Time	13	14	15	16	17	18	19	20	21	22	23	24
$\Delta P_{g=3}$	0.281	0.295	0.349	0.42	0.423	0.328	0.32	0.231	0.231	0.145	0	0

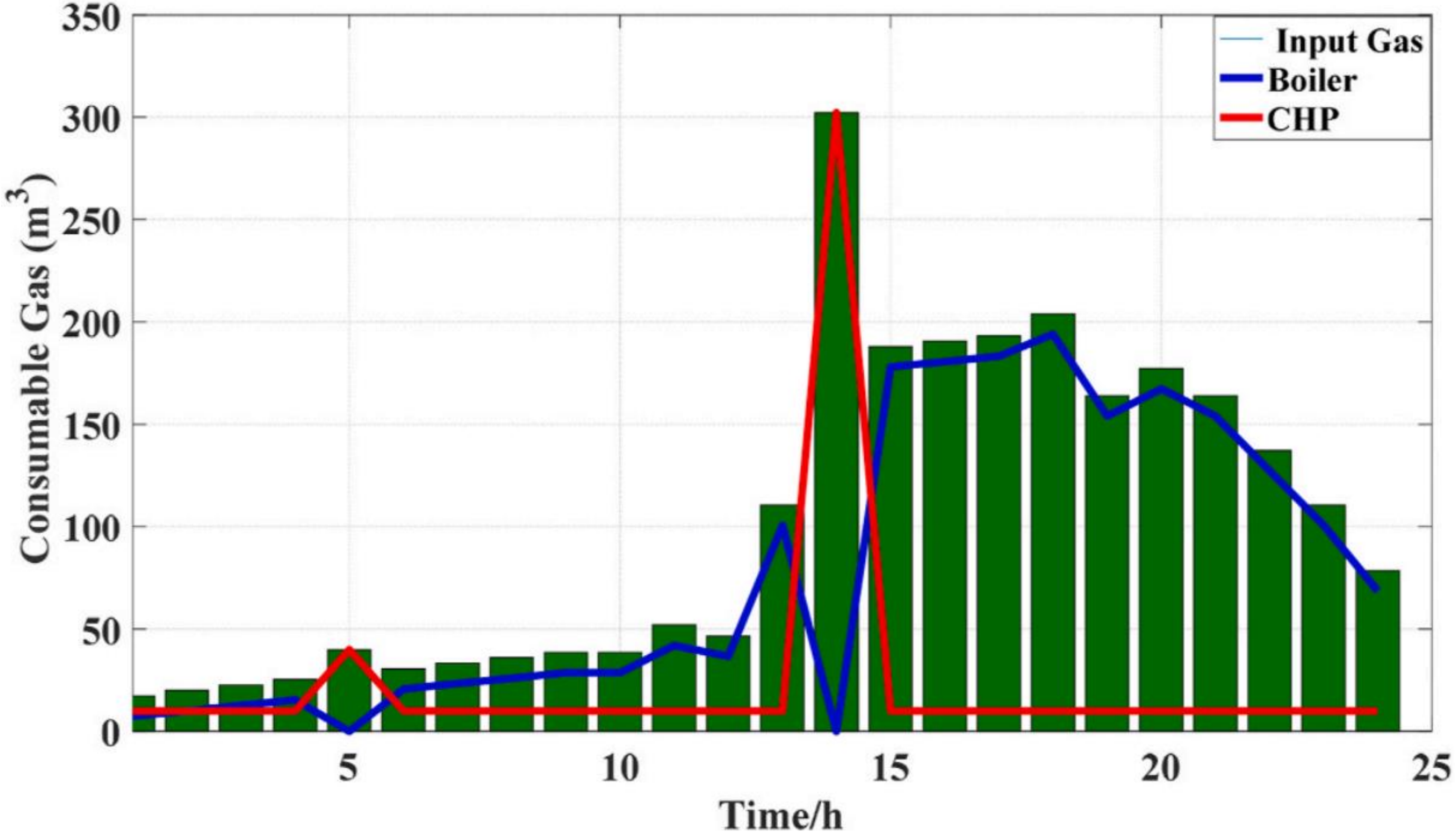
Evaluation of The Proposed Energy Strategy

- Computation result for proposed model for 6-bus system

Propused Model												
Time	1	2	3	4	5	6	7	8	9	10	11	12
$\Delta P_{g=1}$	0	0	0	0	0	0	0	0	0	0.076	0	0
Time	13	14	15	16	17	18	19	20	21	22	23	24
$\Delta P_{g=1}$	0	0	0	0	0	0	0	0	0	0	0	0
Time	1	2	3	4	5	6	7	8	9	10	11	12
$\Delta P_{g=3}$	0	0	0	0	0	0	0	0	0	0.024	0.141	0.218
Time	13	14	15	16	17	18	19	20	21	22	23	24
$\Delta P_{g=3}$	0.281	0.295	0.349	0.42	0.423	0.328	0.32	0.231	0.231	0.126	0	0

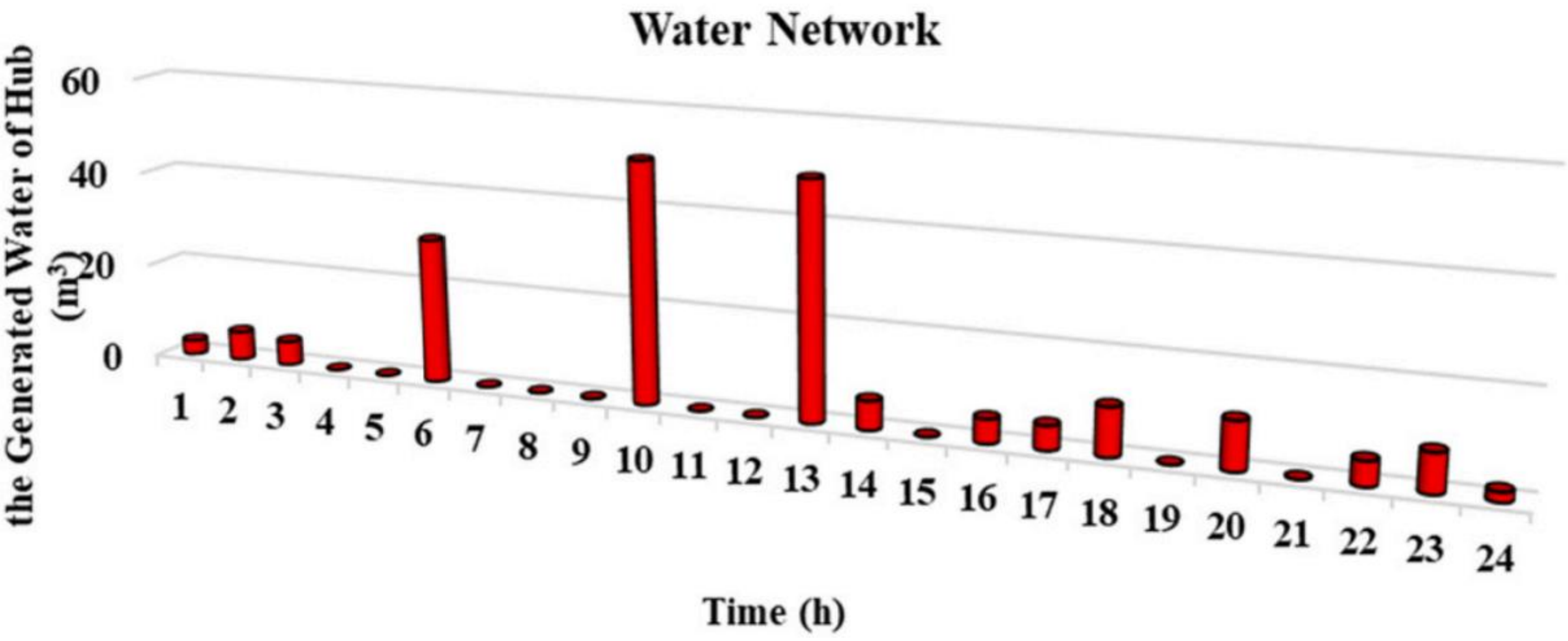
Energy transaction analysis of the water-power system

- The consumption gas of the CHP, boiler and input units.



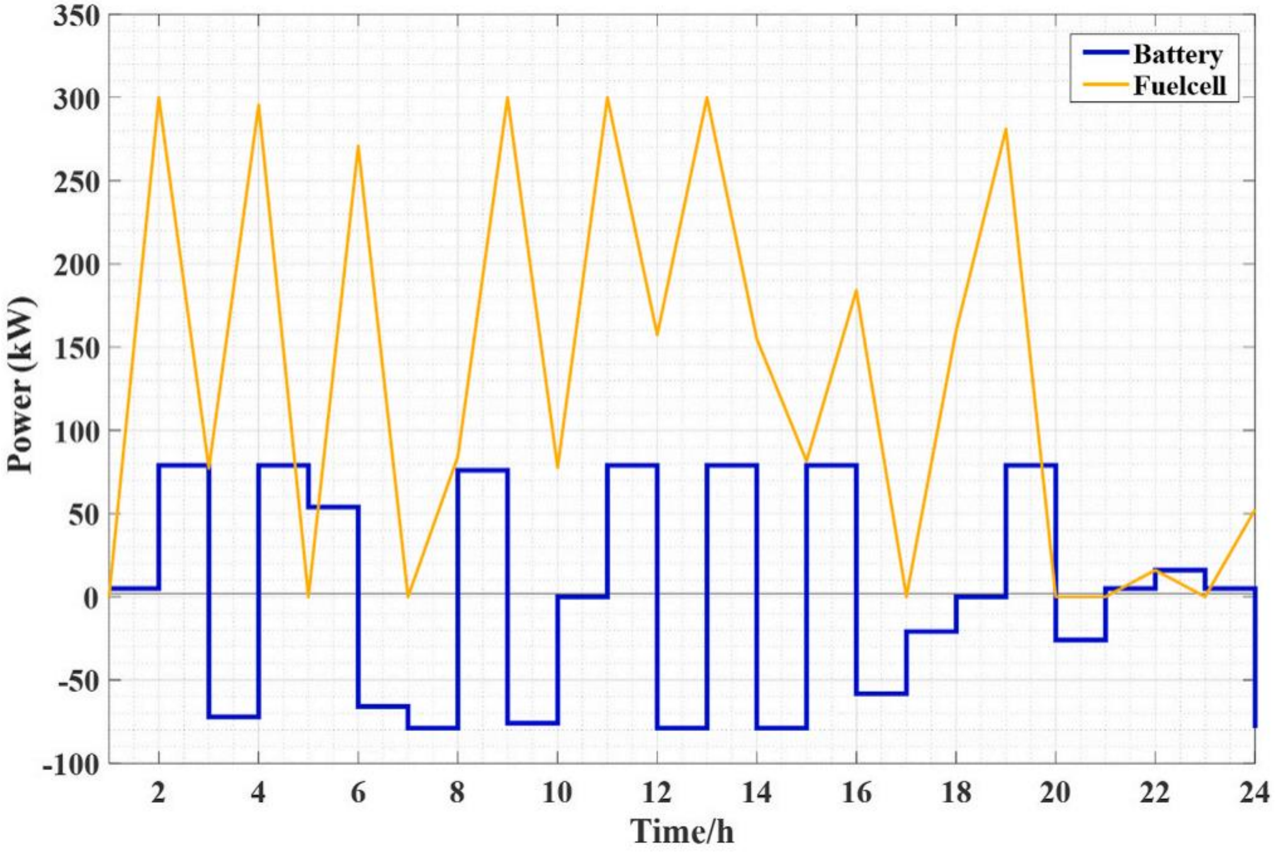
Energy transaction analysis of the water-power system

- The generated water.



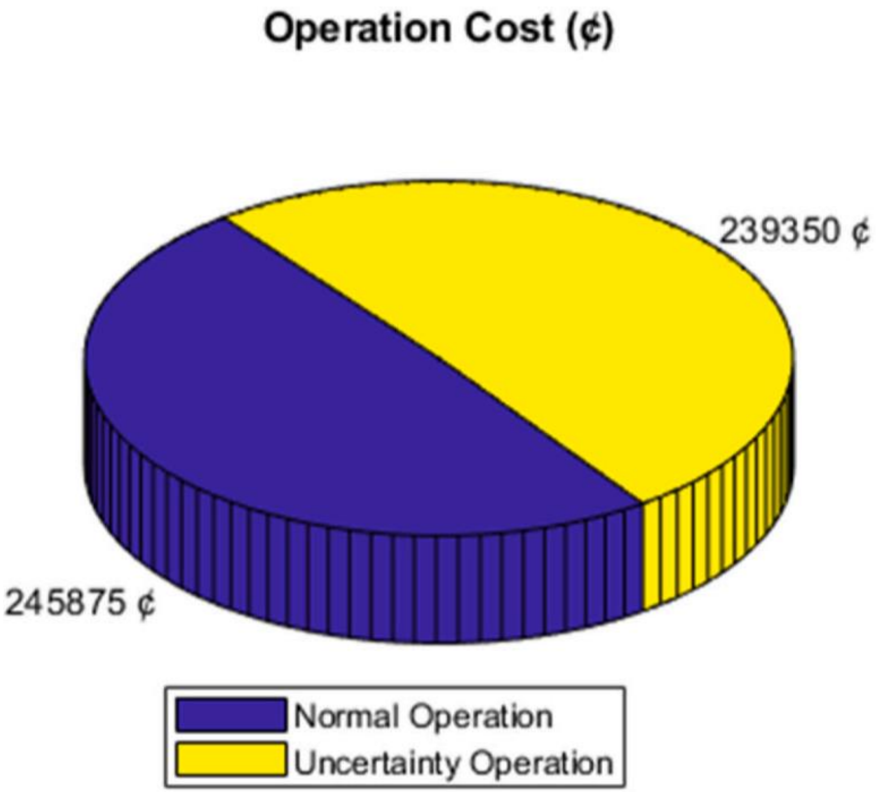
Energy transaction analysis of the water-power system

- The injected powers of fuel cell and storage units.



The simulation of the uncertainty model

- The cost of energy for both normal and uncertainty conditions.



Conclusion

- **We proposed a coefficient congestion-based water-power energy strategy to amend the transmission switching within the power systems**

- **We represented a UT-based uncertainty strategy to model the high-risk multi-energy demands within the based electrical grid connected to the water-power system**

- **We modeled linking energy management for multi-energy demands based on the water-power energy system to be effective for improving the line congestion during the grid-connected mode.**

Future Work

- **Cybersecurity applications**
- **Integration with Advanced Renewable Energy Sources**
- **Enhanced Uncertainty Modeling**
- **Economic and Policy Implications**

List of Publications

- Niaki, A. A., & Jamil, M. (2024). An efficient hydrogen-based water-power strategy to alleviate the number of transmission switching within smart grid. International Journal of Hydrogen Energy, 70, 347-356. https://doi.org/10.1016/j.ijhydene.2024.05.024

- Niaki, A. A., Parsibenehkohal, R., & Jamil, M. (2024, May). Power Loss Reduction Using Distributed Generation Sources Considering Protection Coordination and Harmonic Limits. In 2024 12th International Conference on Smart Grid (icSmartGrid) (pp. 675-681). IEEE.


ANY
QUESTIONS?