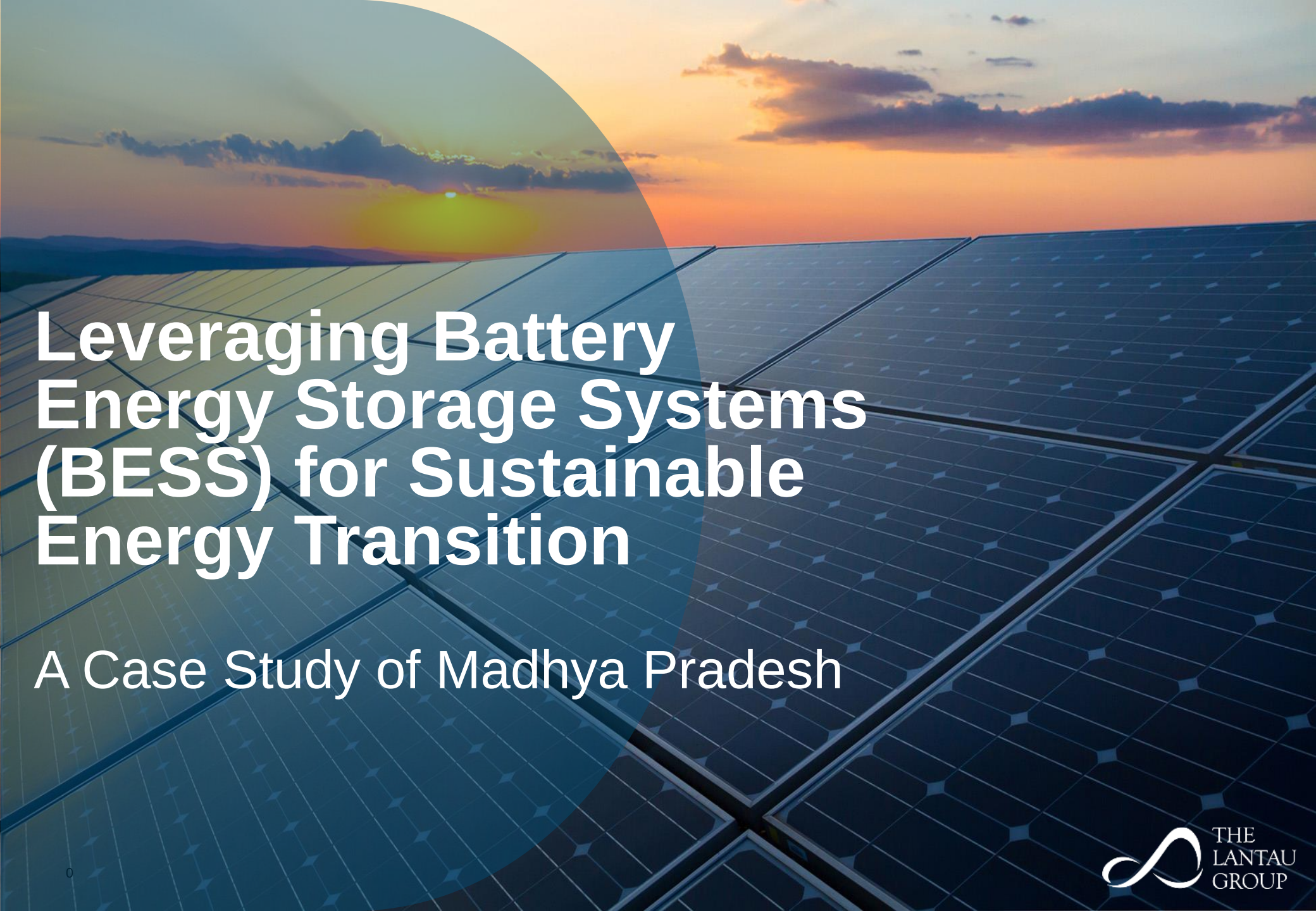

Leveraging Battery Energy Storage Systems (BESS) for Sustainable Energy Transition

A Case Study of Madhya Pradesh

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Potential benefits of Storage Systems in Electricity Grids

- Energy Arbitrage
- Ancillary Services
- Obviates Transmission Investments
- Obviates variable costs of conventional power plants & STOA (including cycling costs)
- Balancing Services

Configuration of Capacity Expansion Planning model – Madhya Pradesh

100+ Generators

(Including state generators, ISGS, RE plants, Storage and STOA)

150 Nodes

(220kV and above substations)
1 ISTS node, 149 STU node

380+ Lines

(Existing and proposed transmission lines. Intra and Inter state transmission network to be modelled)

12 Representative days/year
For 10 years
2025-2035

Objective

Minimize the overall cost (investment + operations) for the study period (i.e., 2025-2035), while maintaining technical, transmission & AS constraints demand-supply balance.

Cost includes

- **CAPEX** of generation and transmission assets
- **Fixed cost** of generators and transmission lines (Includes operational & maintenance cost)
- **Variable cost** of generators
- **Reserve cost**
- **Startup and shutdown cost**
- **Carbon cost**
- Penalties due to:
  - RE curtailment
  - Unserved **load cost**
  - Unserved **reserve cost**

Key Features of our model

- **Co-optimization** of energy and ancillary services
- Planned **transmission and generation capacities**
- **Zonal level planning for RE and storage (state and central nodes)**
- **Dynamic SRAS** = 2% of Demand + 3% of RE generation.
- RPO trajectories

Year	RPO	RPO_DRE
2025	28%	2%
2026	31%	2%
2027	33%	3%
2028	36%	3%
2029	37%	4%
2030	39%	5%
2031	41%	5%
2032	42%	6%
2033	42%	6%
2034	43%	7%
2035	44%	7%

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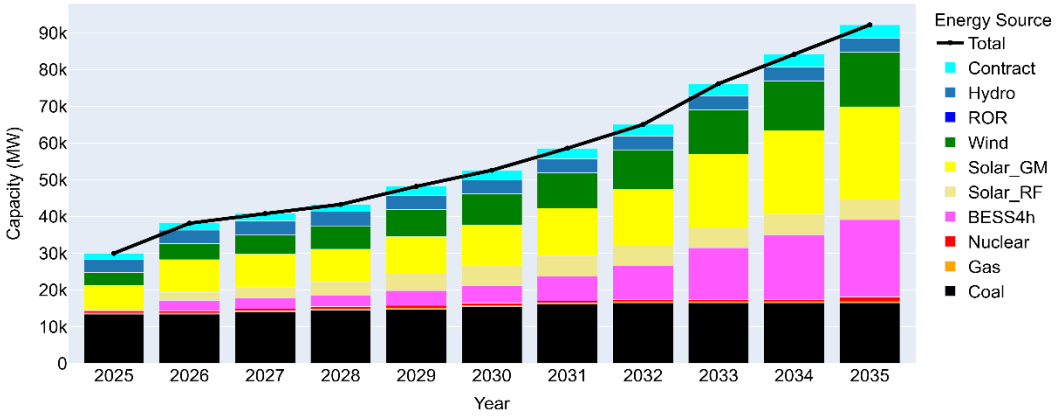
Storage system facilitate a greener expansion path

WITH STORAGE CANDIDATES

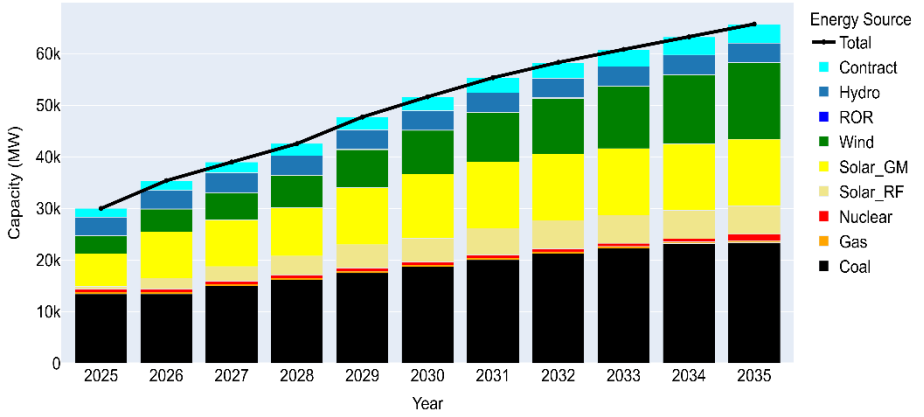
Total Capacities by Energy Source in MW



Energy Source	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	13424	13424	13981	14547	14826	15469	16087	16508	16508	16508	16508
Gas	363	363	363	363	363	363	363	363	363	363	363
Nuclear	586	586	586	586	586	586	586	586	586	586	1286
BESS4h	0	2792	2942	2983	4037	4799	6710	9049	14055	17575	20956
Solar_RF	499	2116	2857	3656	4541	5499	5499	5499	5499	5499	5499
Solar_GM	6370	9005	9005	9005	10198	10948	13051	15339	19993	22939	25276
Wind	3438	4338	5283	6275	7317	8411	9560	10766	12032	13362	14758
ROR	93	93	93	93	93	93	93	93	93	93	93
Hydro	3520	3564	3748	3748	3748	3748	3748	3748	3748	3748	3748
Contract	1700	1900	1948	2051	2500	2700	2900	3100	3300	3500	3700
Total	29993	38180	40805	43307	48208	52615	58597	65051	76178	84173	92188

WITHOUT STORAGE CANDIDATES

Total Capacities by Energy Source in MW



Energy Source	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	13424	13424	14956	16156	17484	18684	20044	21244	22282	23180	23371
Gas	363	363	363	363	363	363	363	363	363	363	363
Nuclear	586	586	586	586	586	586	586	586	586	586	1286
Solar_RF	499	2116	2857	3656	4541	4541	5153	5499	5499	5499	5499
Solar_GM	6370	9005	9005	9372	11083	12499	12883	12891	12891	12891	12891
Wind	3438	4338	5283	6275	7317	8411	9560	10766	12032	13362	14758
ROR	93	93	93	93	93	93	93	93	93	93	93
Hydro	3520	3564	3748	3748	3748	3748	3748	3748	3748	3748	3748
Contract	1700	1900	2100	2300	2500	2700	2900	3100	3300	3500	3700
Total	29993	35388	38990	42548	47714	51624	55329	58289	60794	63222	65709

- **Energy storage systems**, especially Battery Energy Storage Systems (BESS), facilitate a greener expansion path by enabling greater integration of solar power.
- **Solar capacity installations** are significantly prioritized and expanded in scenarios supported by storage solutions.
- **Wind capacity** reaches its maximum allowable limit due to its critical role in supplying electricity during periods without solar availability.
- **Additional coal-based generation capacity** becomes necessary to ensure system reliability when storage technologies are absent.

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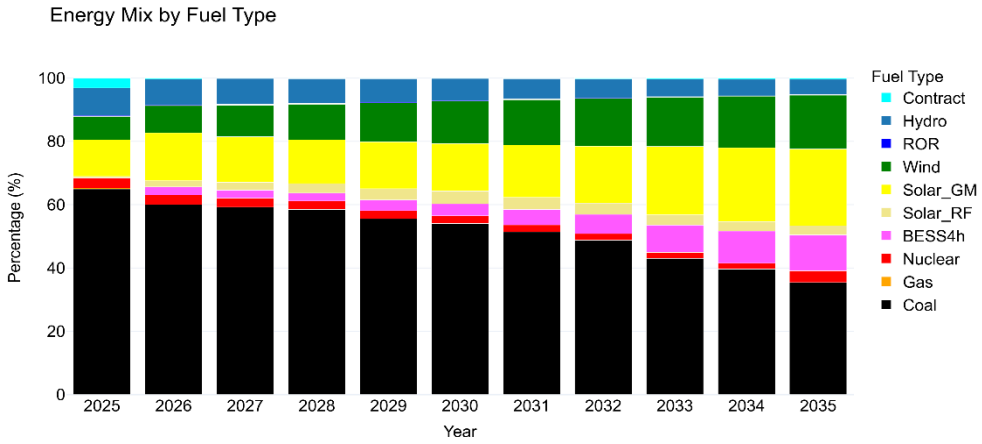
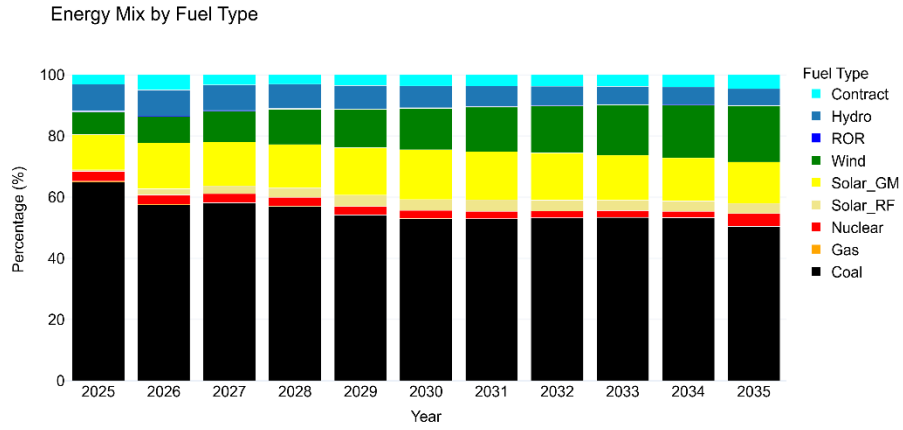
Energy Storage Systems Enable Higher Renewable Integration and Reduced Coal Dependence

WITH STORAGE CANDIDATES



Energy Source	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	64.91	60.05	59.21	58.45	55.53	54.04	51.36	48.73	43	39.67	35.38
Gas	0.31	0				0.01	0.01	0.01	0.01	0.01	0.01
Nuclear	3.22	2.97	2.83	2.71	2.55	2.41	2.23	2.07	1.91	1.8	3.73
BESS4h		2.57	2.5	2.5	3.41	3.76	4.9	6.12	8.59	10.14	11.33
Solar_RF	0.5	1.94	2.5	3.05	3.58	4.08	3.79	3.52	3.25	3.05	2.88
Solar_GM	11.54	15.11	14.42	13.78	14.76	14.95	16.52	18.01	21.62	23.29	24.24
Wind	7.39	8.58	9.95	11.27	12.38	13.42	14.34	15.11	15.59	16.27	17
ROR	0.29	0.27	0.26	0.25	0.23	0.22	0.2	0.19	0.17	0.16	0.16
Hydro	8.75	8.15	8.15	7.79	7.35	6.92	6.42	5.96	5.5	5.16	4.85
Contract	3.1	0.35	0.18	0.2	0.2	0.21	0.23	0.28	0.36	0.44	0.42

WITHOUT STORAGE CANDIDATES



Energy Source	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	64.91	57.44	58.05	56.97	54.12	52.98	52.82	53.11	53.33	53.18	50.31
Gas	0.31	0.2	0.13	0.16	0.16	0.17	0.16	0.14	0.13	0.12	0.11
Nuclear	3.22	3.07	2.92	2.79	2.66	2.52	2.37	2.23	2.11	2.02	4.25
Solar_RF	0.5	2	2.57	3.15	3.73	3.53	3.76	3.56	3.41	3.42	3.28
Solar_GM	11.52	15	14.34	14.14	15.52	16.28	15.79	15.41	14.7	14.1	13.53
Wind	7.4	8.65	10.08	11.51	12.51	13.56	14.51	15.3	16.34	17.29	18.37
ROR	0.29	0.27	0.25	0.23	0.2	0.19	0.18	0.18	0.18	0.17	0.16
Hydro	8.75	8.42	8.38	8	7.6	7.16	6.71	6.3	5.97	5.71	5.44
Contract	3.1	4.96	3.27	3.05	3.49	3.62	3.7	3.77	3.84	3.99	4.55

- **Reduced Coal Dependency**: The share of coal in the energy mix declines to 35% with the integration of storage systems, driven by:
- Provision of peaking and ramping capabilities by storage, minimizing reliance on coal-fired plants.
- Enhanced adoption and utilization of renewable energy (RE) sources.
- **Decreased Reliance on Short-Term Contracts**: Contribution of short-term open access (STOA) contracts significantly decreases to 0.42% with BESS, compared to 4.55% without storage solutions.
- **Increased Solar Contribution**: Greater solar capacities result in a higher overall share of solar energy within the total energy mix, bolstered by the presence of energy storage.

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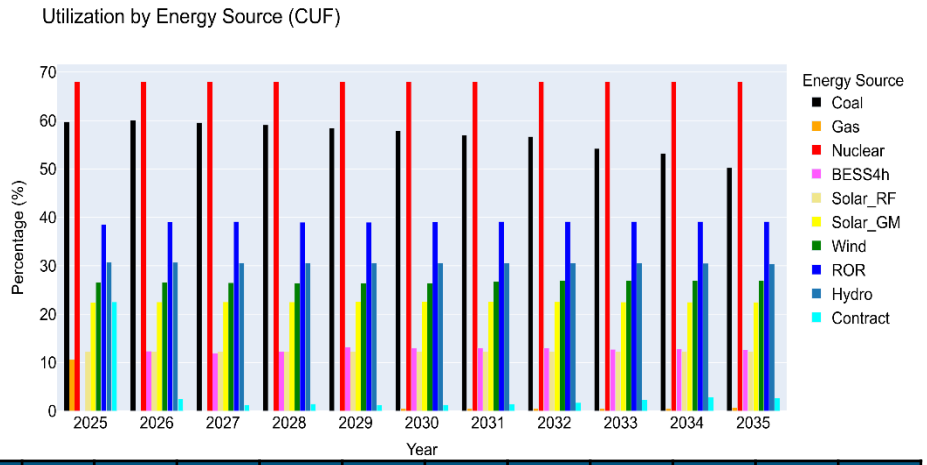
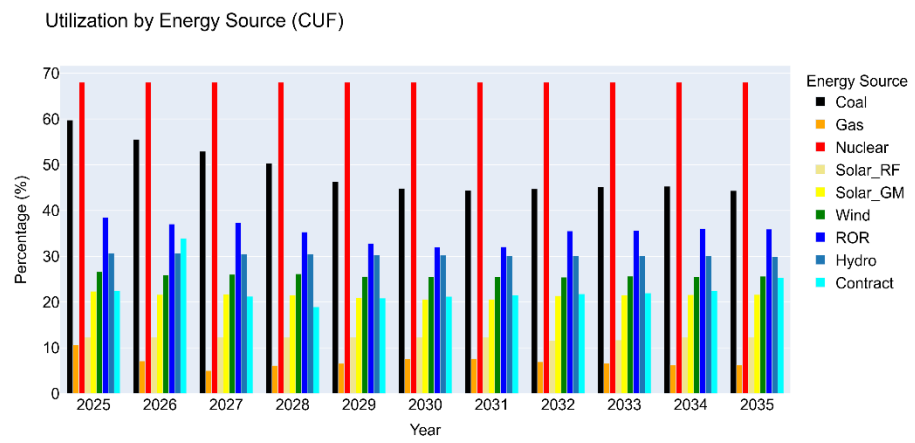
Optimized Coal Utilization and Reduced Short-term Market Dependence via Energy Storage

WITH STORAGE CANDIDATES



Energy Source	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	59.76	60.03	59.57	59.12	58.43	57.88	56.95	56.7	54.21	53.24	50.24
Gas	10.61	0.07	0	0	0	0.48	0.48	0.48	0.48	0.48	0.76
Nuclear	68	68	68	68	68	68	68	68	68	68	68
BESS4h	0	12.37	11.96	12.32	13.18	12.97	13.02	13	12.73	12.79	12.68
Solar_RF	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29
Solar_GM	22.39	22.52	22.53	22.52	22.59	22.62	22.58	22.56	22.51	22.5	22.48
Wind	26.56	26.56	26.49	26.44	26.4	26.44	26.75	26.96	26.96	26.97	27.01
ROR	38.52	39.07	39.13	38.98	38.98	39.09	39.13	39.13	39.13	39.13	39.13
Hydro	30.7	30.68	30.58	30.58	30.58	30.58	30.56	30.56	30.55	30.5	30.37
Contract	22.53	2.49	1.29	1.47	1.23	1.3	1.43	1.73	2.3	2.81	2.66

WITHOUT STORAGE CANDIDATES



Energy Source	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	59.76	55.55	52.93	50.3	46.3	44.87	44.35	44.73	45.17	45.28	44.33
Gas	10.61	7.11	5.01	6.13	6.58	7.61	7.64	6.93	6.65	6.27	6.25
Nuclear	68	68	68	68	68	68	68	68	68	68	68
Solar_RF	12.29	12.29	12.29	12.29	12.29	12.29	12.29	11.59	11.7	12.29	12.29
Solar_GM	22.36	21.62	21.71	21.52	20.94	20.6	20.62	21.38	21.53	21.59	21.62
Wind	26.61	25.89	26.02	26.17	25.57	25.5	25.55	25.42	25.64	25.54	25.63
ROR	38.49	37.05	37.32	35.32	32.82	32	32.07	35.53	35.6	36.06	35.93
Hydro	30.7	30.68	30.5	30.46	30.34	30.21	30.14	30.08	30.05	30.08	29.91
Contract	22.53	33.89	21.24	18.94	20.86	21.22	21.47	21.78	21.98	22.53	25.33

•**Enhanced Coal Asset Utilization**: Existing coal-fired capacities are utilized more efficiently with the integration of energy storage systems.
•**Lower Short-term Contract Requirements**: Utilization of short-term open access (STOA) contracts reduces to 2.66% due to Battery Energy Storage Systems (BESS) effectively addressing the system's peaking and ramping needs.

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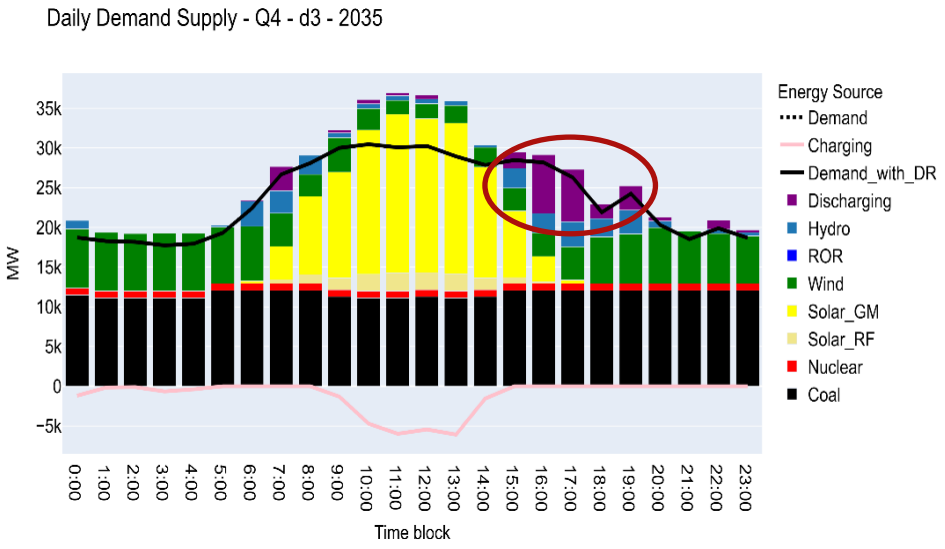
BESS reduces coal generation, associated cycling, and contract dependency

WITH STORAGE CANDIDATES



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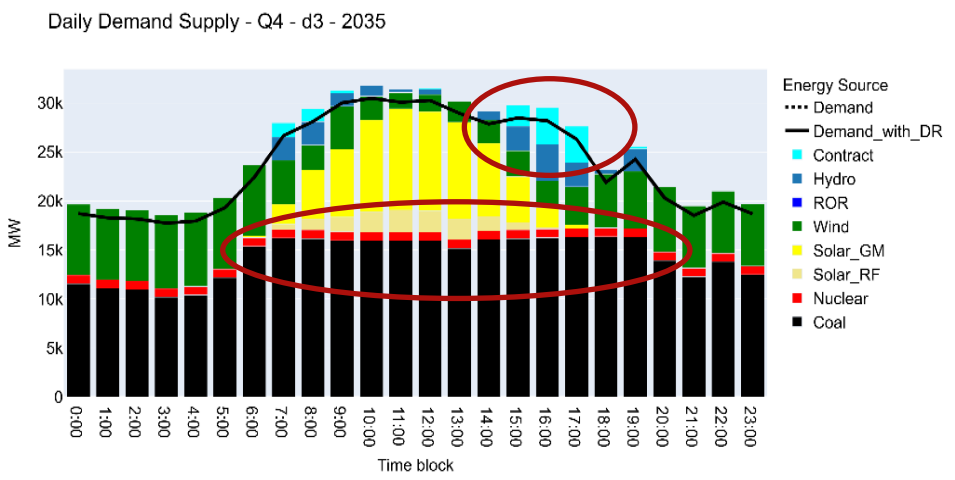


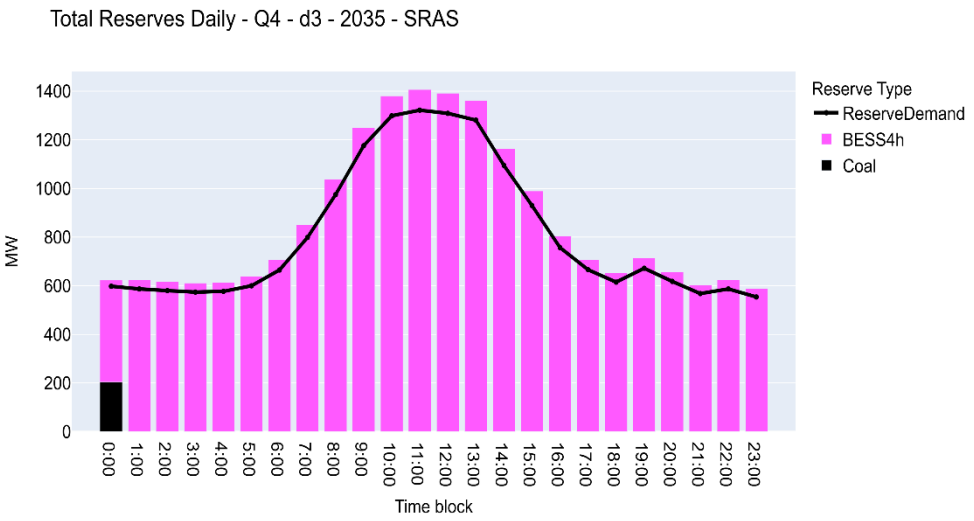
•**Reduced Coal Dependency:**
Battery Energy Storage Systems (BESS) eliminate the necessity for additional coal-based generation capacity and lessen the reliance on short-term procurement contracts (STOA), by effectively managing system load variations.

•Enhanced solar capacity deployment, supported by BESS, results in surplus renewable generation. This surplus is efficiently shifted by storage systems to meet demand during peak and ramping periods.

•**Mitigating Additional Coal Requirements:**
In scenarios lacking BESS, the system is compelled to rely on an estimated additional coal-based generation of around 5 GW per hour, coupled with increased dependency on short-term contract procurements, thereby highlighting the critical role of storage technologies in achieving sustainable energy operations.

Flexible BESS Optimizes System Reserves and Reduces Reliance on Coal Capacities

WITH STORAGE CANDIDATES



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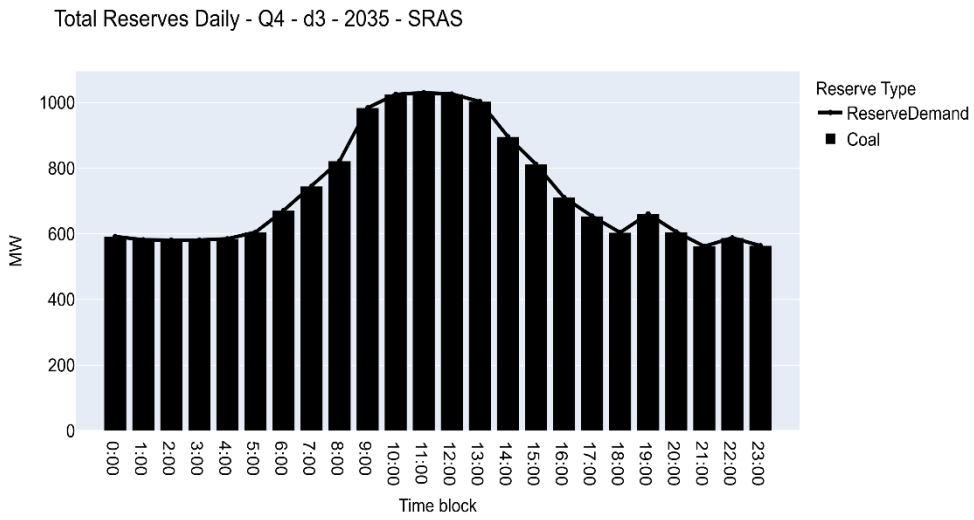

•Preferred Source for Reserves:
Flexible Battery Energy Storage Systems (BESS) effectively fulfill system reserve requirements, offering a responsive and sustainable alternative.

•Reduced Coal Utilization for Reserves:
In systems lacking BESS, coal capacities are deployed to maintain reserves, necessitating additional coal capacity to meet both primary energy demand and ancillary services, thus highlighting the critical advantage provided by storage technologies.

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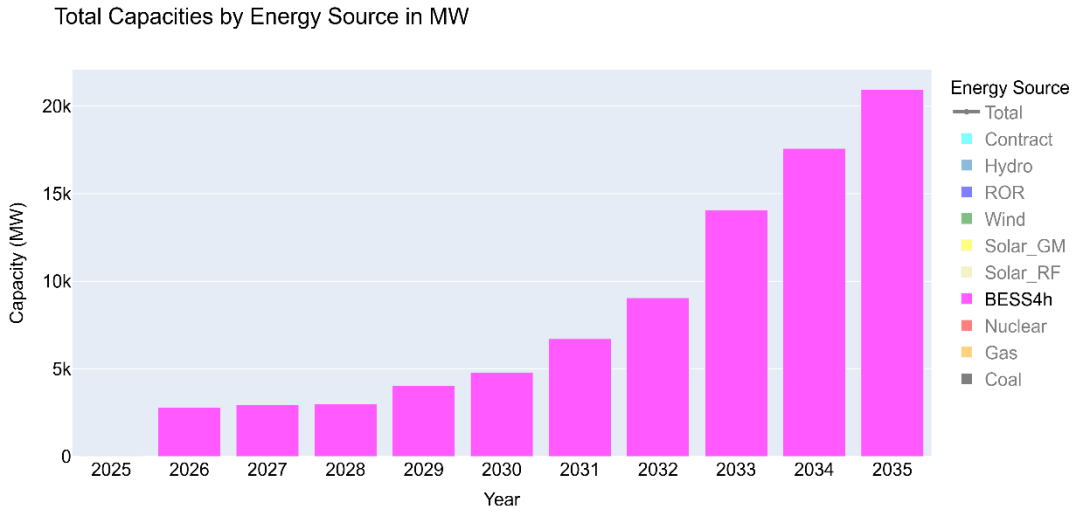
Locations of BESS – BESS at different locations behave differently

Battery Plant	Bus Name	2035 (in MW)
BESS4h_Bharat	ISTS	7794
BESS4h_362048	CHEGAON-42	1048
BESS4h_362079	MAIHAR-2	338
BESS4h_362002	UJJAIN-2	329
BESS4h_362321	KANNOD-220	915
BESS4h_362027	NIMRANI-2	654
BESS4h_362019	DAMOH-2	823
BESS4h_362059	BAIRAGAR-2	674
BESS4h_362135	NTPC 250	2343
BESS4h_362043	SHIVPURI-2	1114
BESS4h_362113	MANDSOUR-42	385
BESS4h_362058	BADNAGAR-2	909
BESS4h_362078	DALODA-2	916
BESS4h_362025	DEWAS-2	904
BESS4h_362091	NIPONIYA-2	899
BESS4h_362121	RATLAM(S)-2	906



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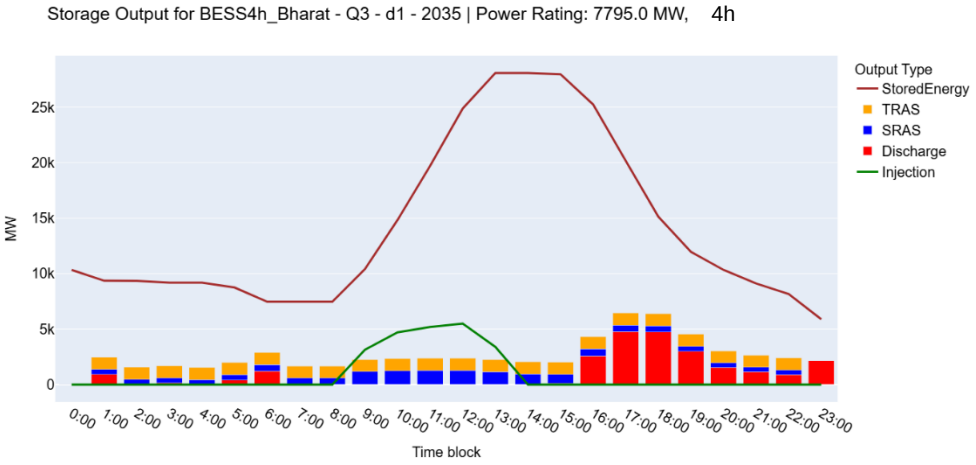
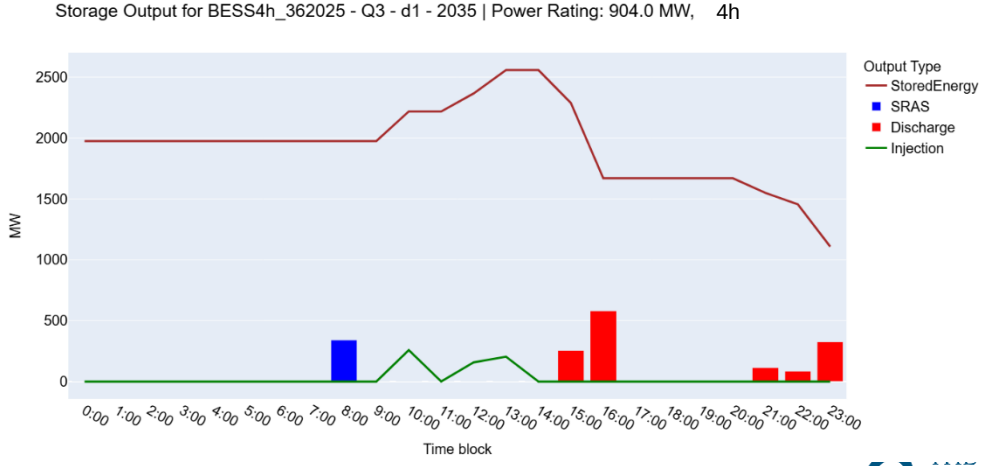


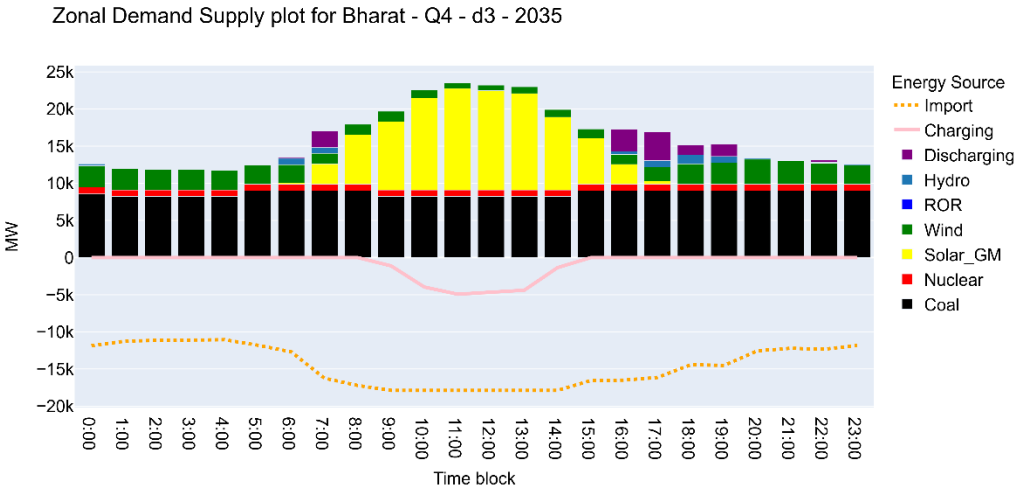
Dewas-2



BESS USES – obviates coal, STOA from ISTS – reduced GNA

ISTS NODE

WITH STORAGE CANDIDATES



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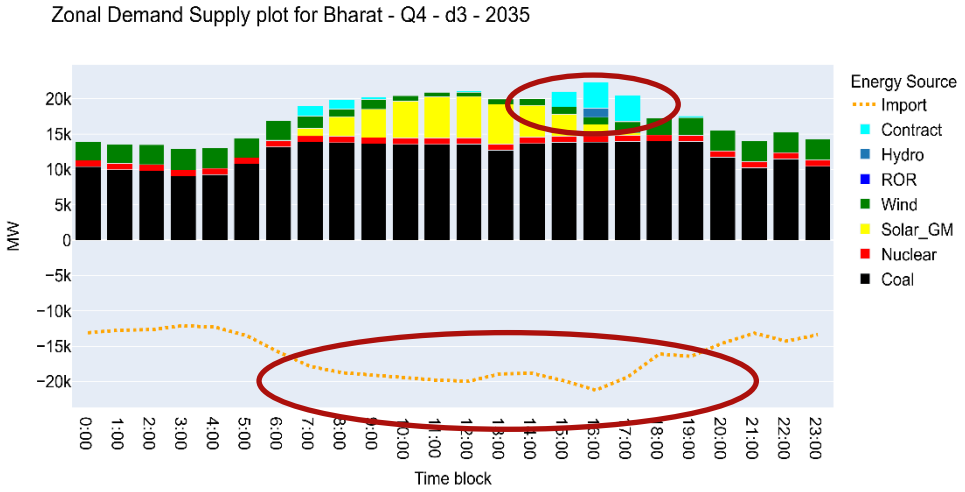

- **Increased Coal Generation and Contracted Power Without BESS:**

In scenarios without BESS, the system necessitates higher coal-fired generation and elevated procurement through Short-Term Open Access (STOA) contracts from ISTS to satisfy demand requirements.

- **Higher Transmission Flows Requiring Infrastructure Augmentation Without BESS:**

Absence of BESS leads to increased power flows from ISTS to STU networks, consequently necessitating capacity enhancements in both STU and ISTS infrastructures. Such augmentations are significantly reduced or avoided altogether in systems designed with integrated storage solutions.

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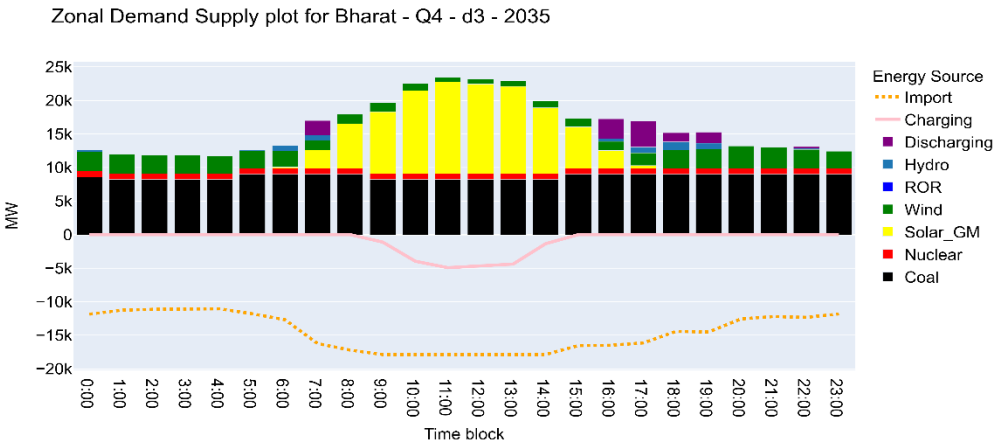
Uses of BESS – 1. Obviates need of coal, STOA – 2. Reduces RE curtailment

- Helps in obviating coal generation – BESS at ISTS node

WITH STORAGE CANDIDATES



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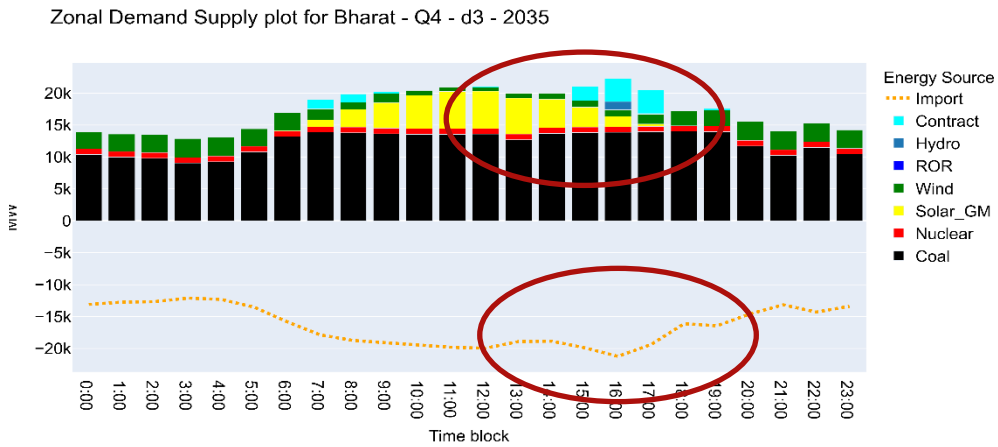
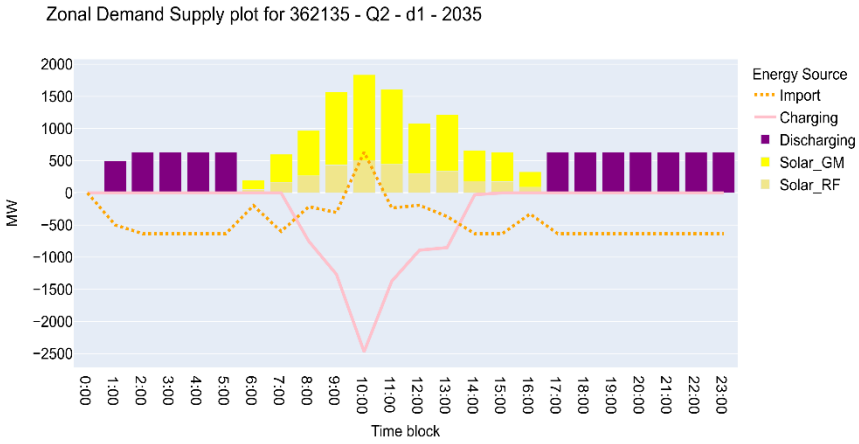
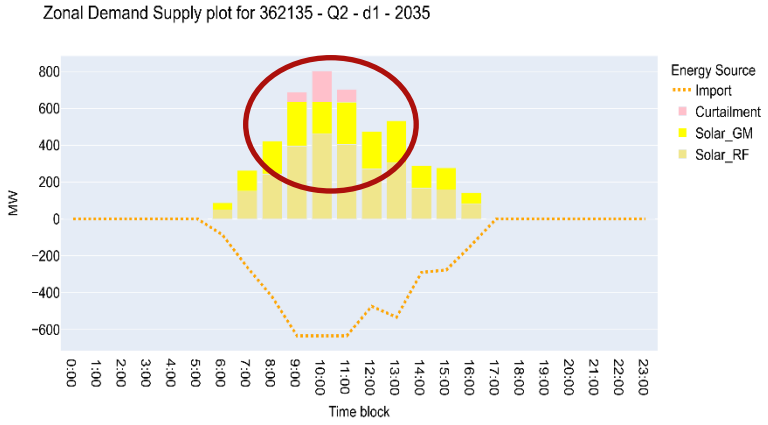


- Reducing RE curtailment and meeting substation demand inside the state – BESS at 362135 – NTPC 250





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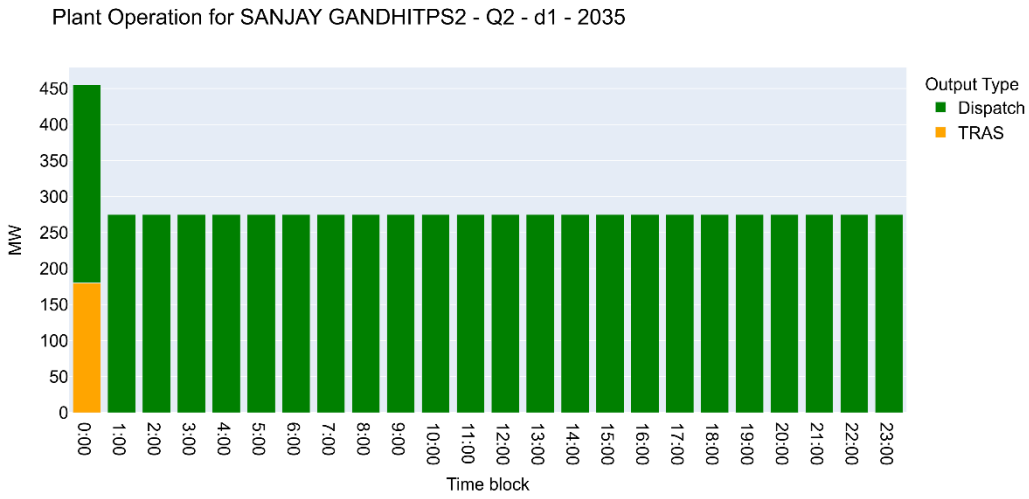
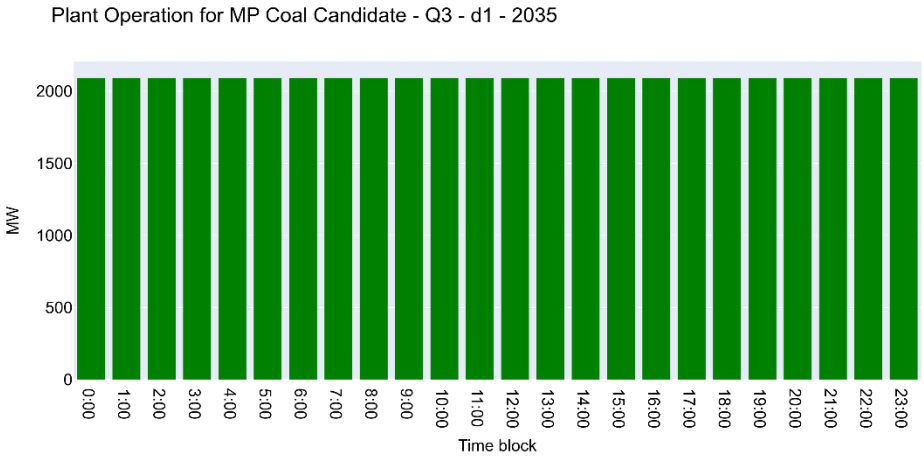
BESS helps smoothen out generation of conventional generators

WITH STORAGE CANDIDATES





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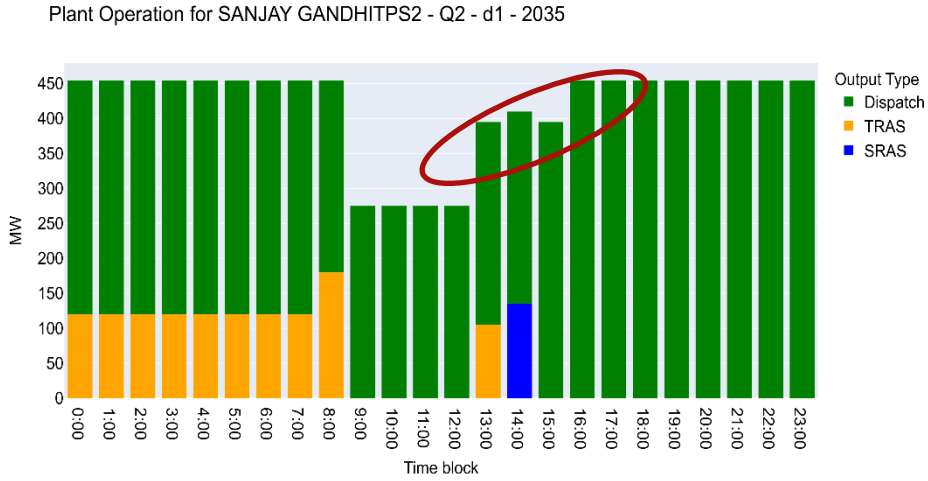

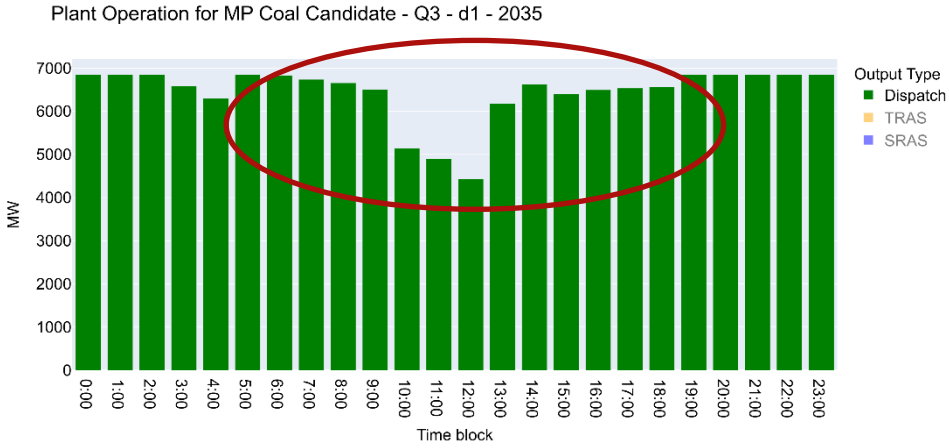

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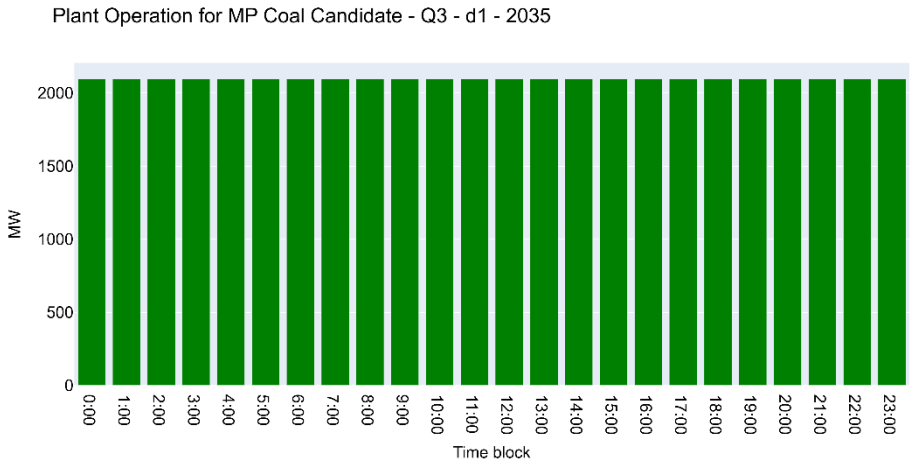
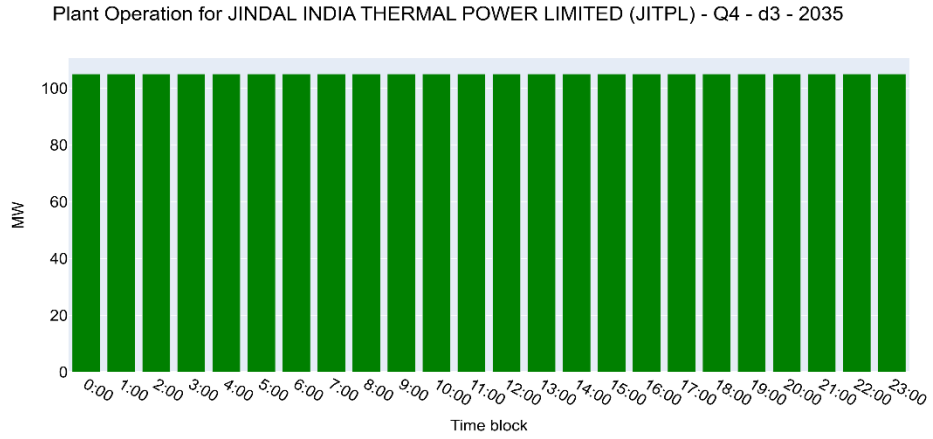
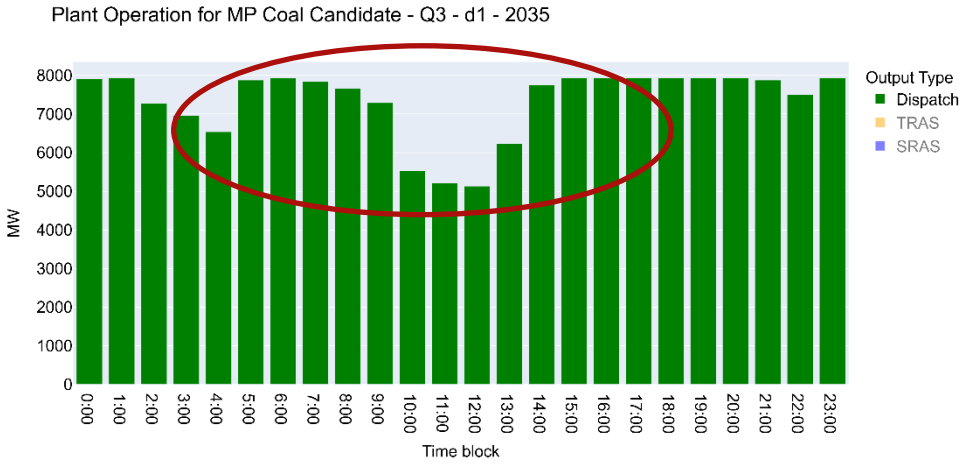
BESS helps smoothen out generation of conventional generators

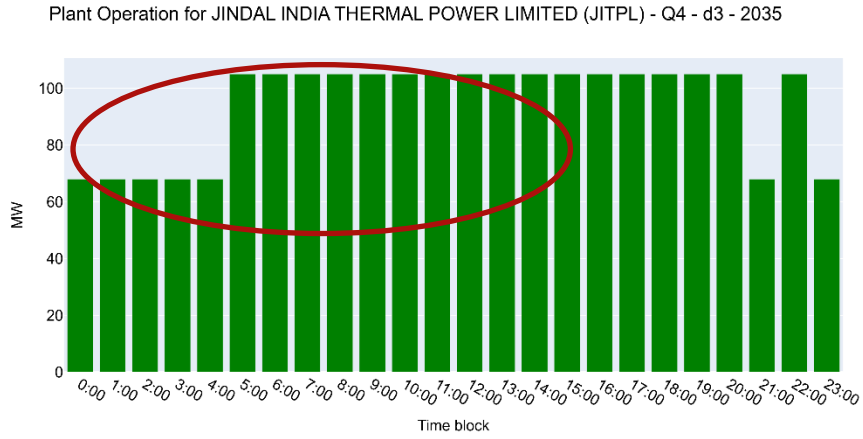
WITH STORAGE CANDIDATES





WITHOUT STORAGE CANDIDATES





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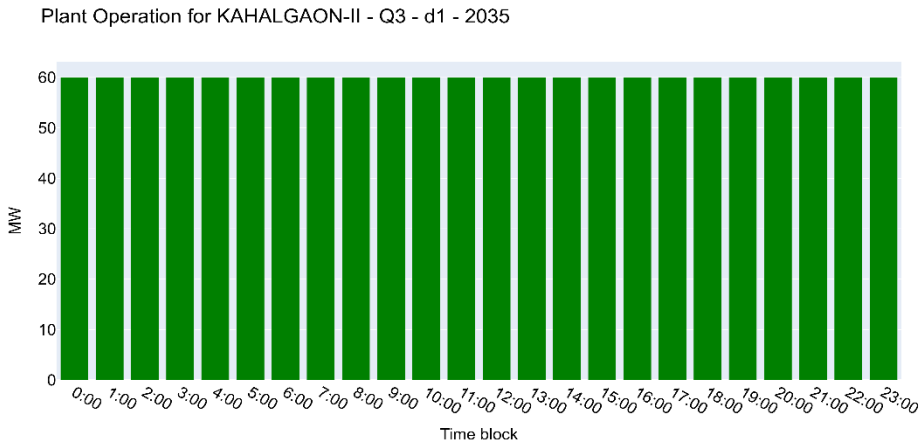
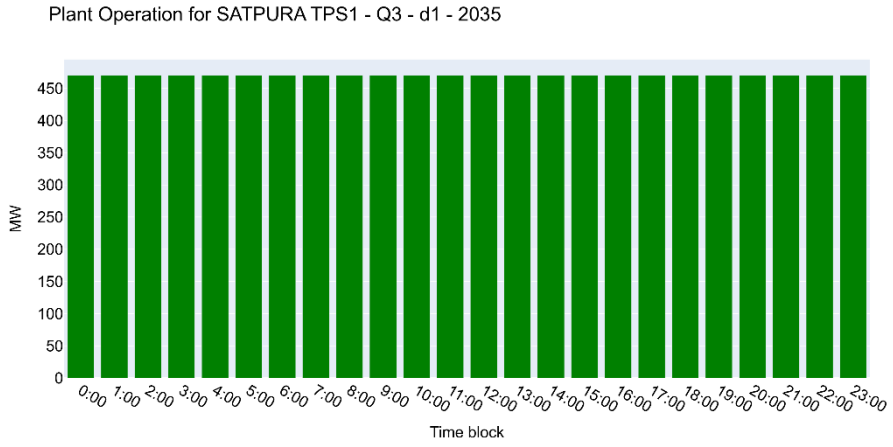
BESS helps smoothen out generation of conventional generators

WITH STORAGE CANDIDATES





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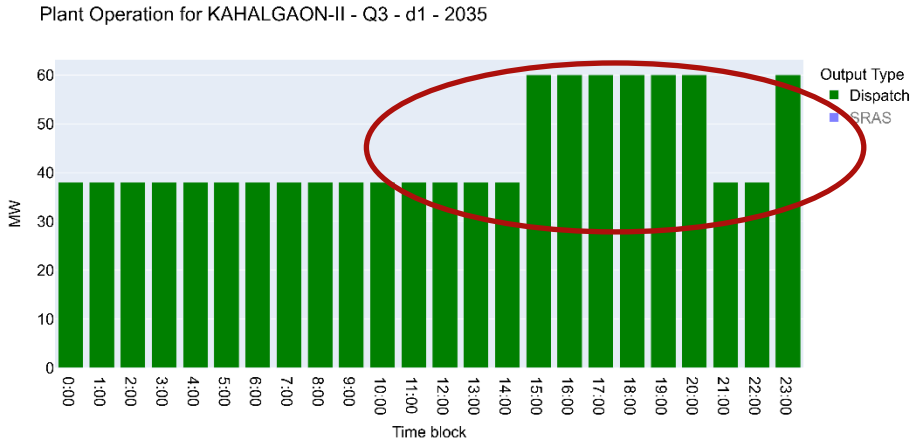

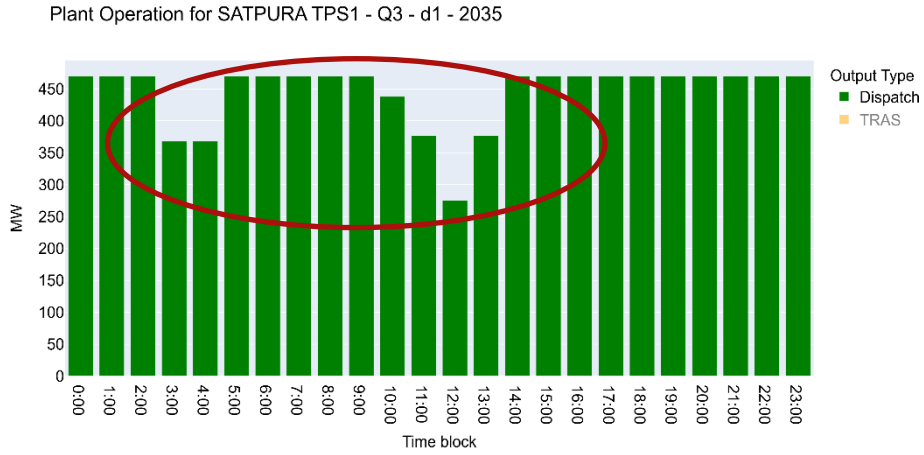

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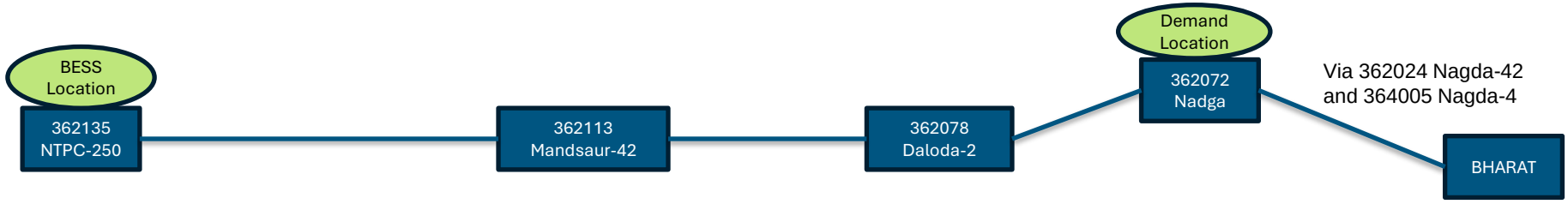
BESS helps in meeting demand of neighboring substation, thus reducing ISTS flows into STU – Q3-d1-2035



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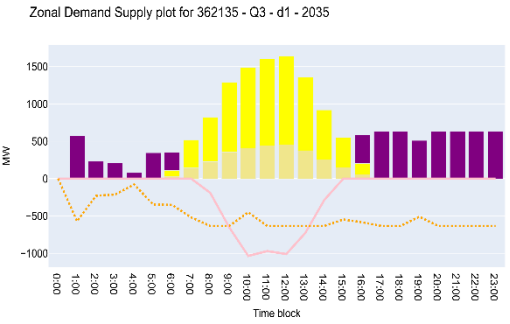

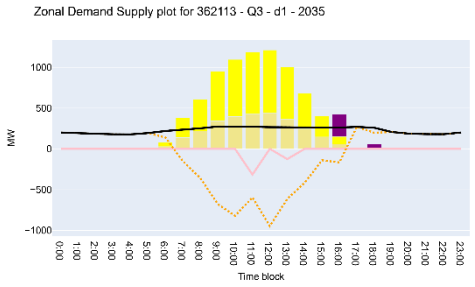

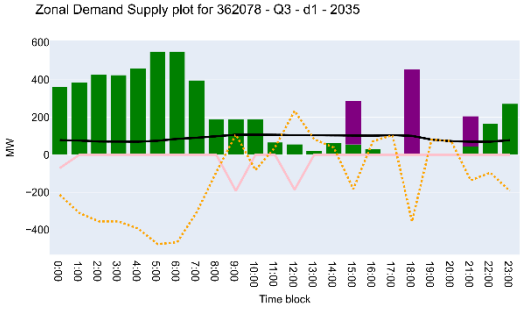

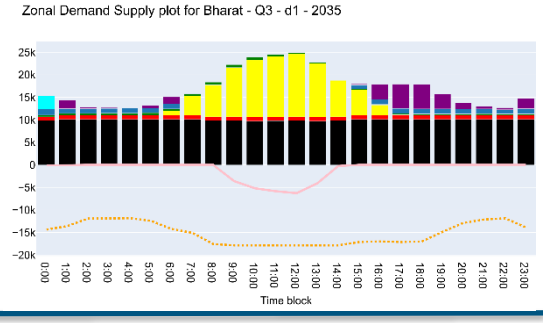

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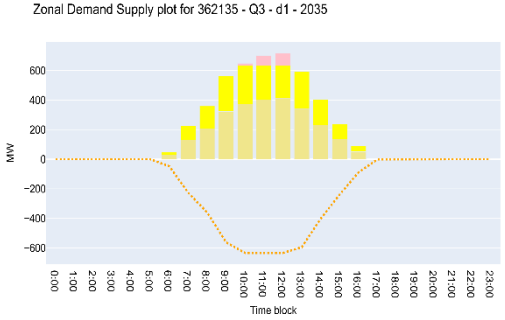

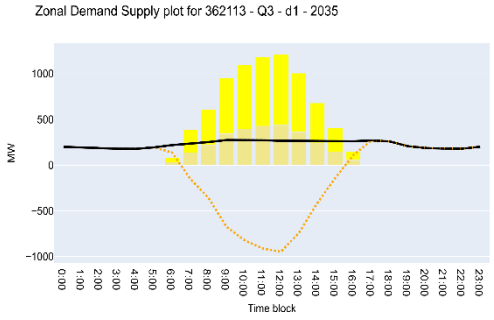

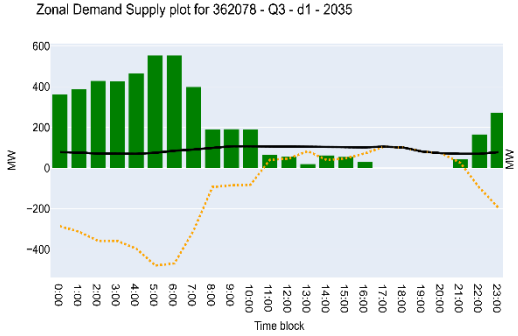

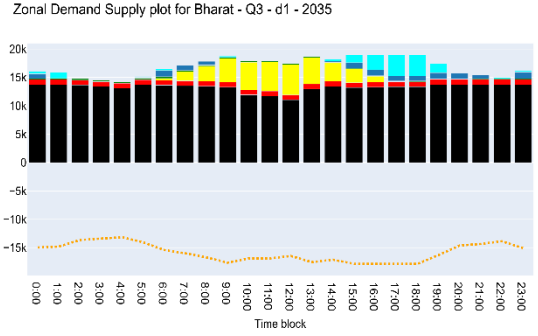

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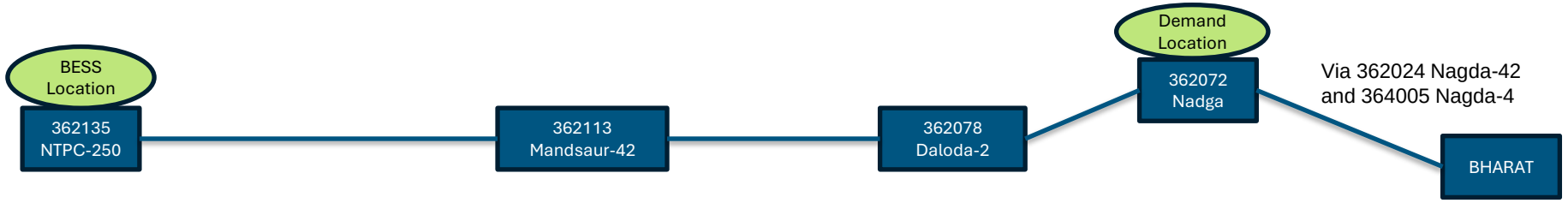
BESS helps in meeting demand of neighboring substation, thus reducing ISTS flows into STU-Q2-d1-2035



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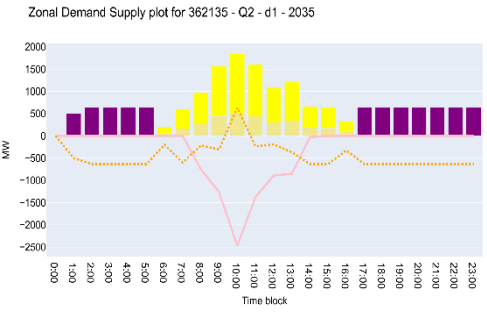

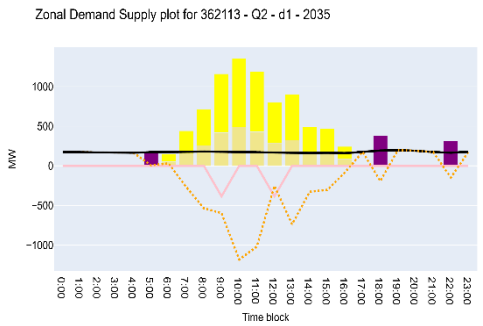

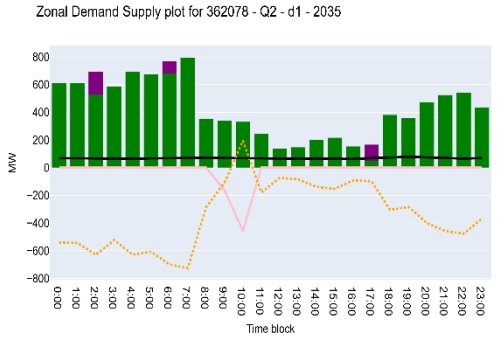

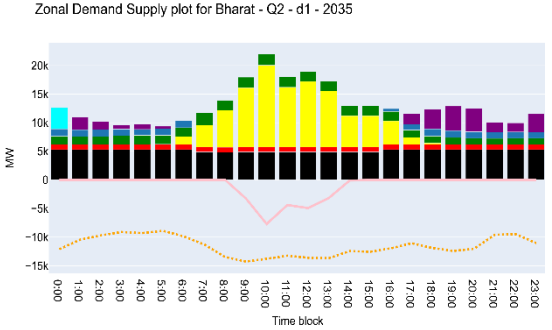

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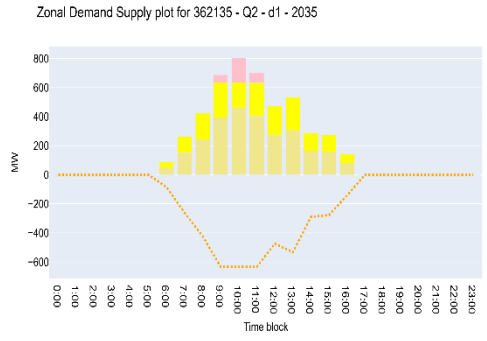

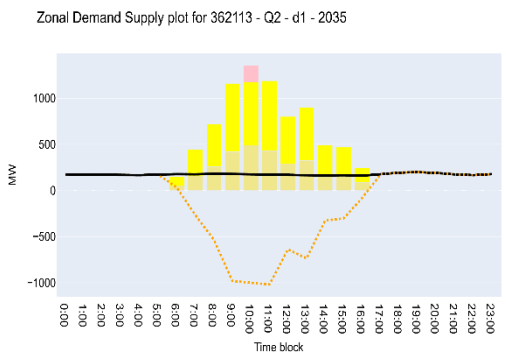

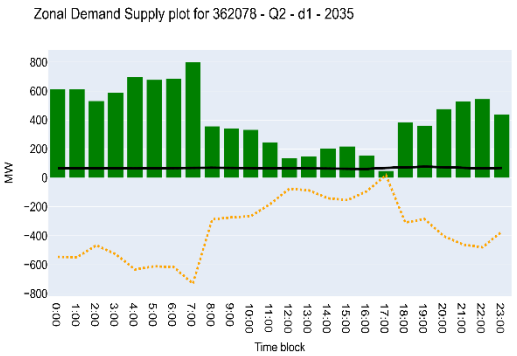

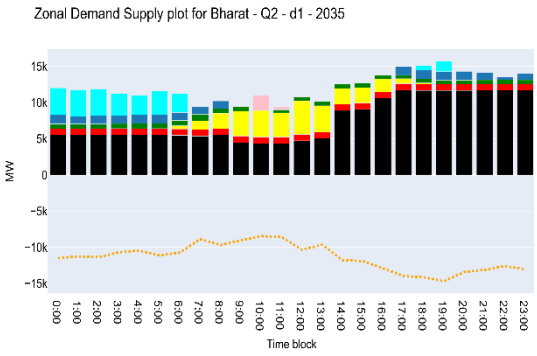

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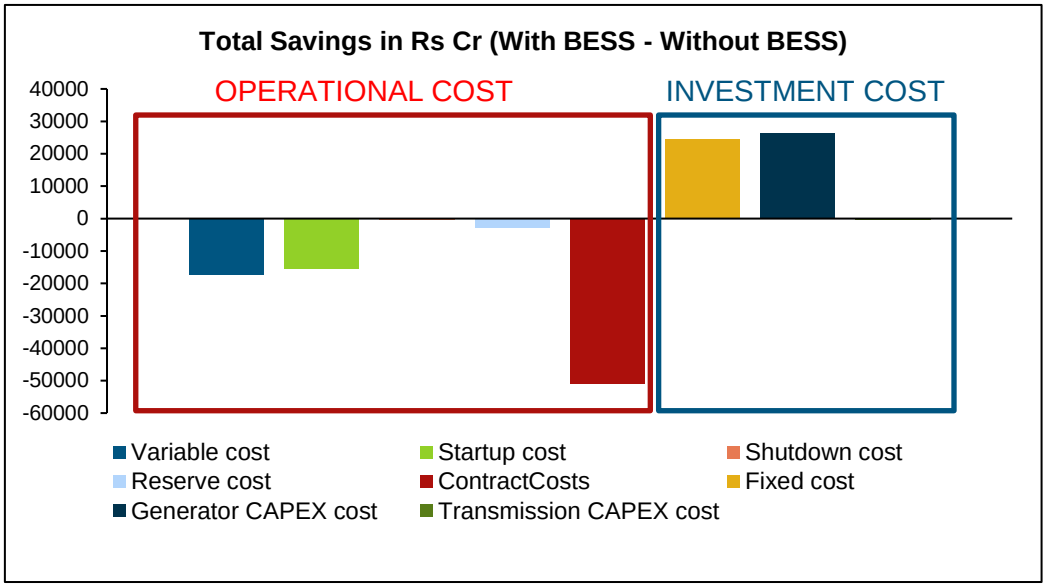
Savings up to INR 36000 Cr. (6.3%) over 10 years in presence of BESS

WITH BESS (in Rs Cr)											
Costs	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Variable cost	21077	21907	24317	26822	28754	31834	34516	37738	38073	39829	41676
Startup cost	595	255	260	291	333	434	484	441	296	217	97
Shutdown cost	15	0	0	0	0	3	3	3	3	3	5
Fixed cost	3559	4725	5133	5502	6312	7151	8453	9971	12633	14818	17232
Curtailment cost	408	11	0	69	56	34	0	0	0	0	0
Generator capex cost	0	3446	4709	5790	7575	9318	11635	14014	17692	20307	23228
Transmission capex cost	0	0	0	0	0	0	0	0	2	4	6
Reserve cost	185	14	14	16	19	20	19	20	19	21	21
Unmet reserves cost	697	0	0	0	0	0	0	0	153	195	200
Unmet RPO cost	4006	0	0	0	0	210	1739	3340	4826	6137	7419
ContractCosts	3356	414	220	263	270	307	364	469	665	861	861

	WITHOUT BESS (in Rs Cr)										
Costs	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Variable cost	21077	20876	23539	25681	26855	29627	33413	38248	43434	48401	52805
Startup cost	595	1052	1240	1443	1782	2102	2158	2193	2268	2265	2176
Shutdown cost	15	21	21	25	30	37	38	36	35	36	38
Fixed cost	3559	3971	4477	4946	5645	6308	7025	7716	8395	9091	9836
Curtailment cost	408	4943	4400	5153	10582	13985	14438	12664	10907	10090	9874
Generator capex cost	0	1762	3520	5062	7102	8750	10398	11804	13049	14242	15615
Transmission capex cost	0	0	0	0	0	0	1	3	83	159	234
Reserve cost	185	202	219	236	255	274	295	317	340	365	389
Unmet reserves cost	697	1623	551	286	256	396	491	680	861	603	709
Unmet RPO cost	4006	0	0	0	0	4338	3230	4681	5964	6137	7419
ContractCosts	3356	5641	3907	3816	4569	5019	5455	5914	6353	6906	8211



	SAVINGS (WITH BESS – WITHOUT BESS) in Rs Cr											
Costs	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	**Total**
Variable cost	0	1031	778	1141	1899	2207	1103	-510	-5361	-8572	-11129	-17413
Startup cost	0	-797	-980	-1152	-1449	-1668	-1674	-1752	-1972	-2048	-2079	-15571
Shutdown cost	0	-21	-21	-25	-30	-34	-35	-33	-32	-33	-33	-297
Fixed cost	0	754	656	556	667	843	1428	2255	4238	5727	7396	24520
Generator capex cost	0	1684	1189	728	473	568	1237	2210	4643	6065	7613	26410
Transmission capex cost	0	0	0	0	0	0	-1	-3	-81	-155	-228	-468
Reserve cost	0	-188	-205	-220	-236	-254	-276	-297	-321	-344	-368	-2709
ContractCosts	0	-5227	-3687	-3553	-4299	-4712	-5091	-5445	-5688	-6045	-7350	-51097

TOTAL SAVING OVER 10 YEARS ~ INR 36000 Cr. (6.3%)

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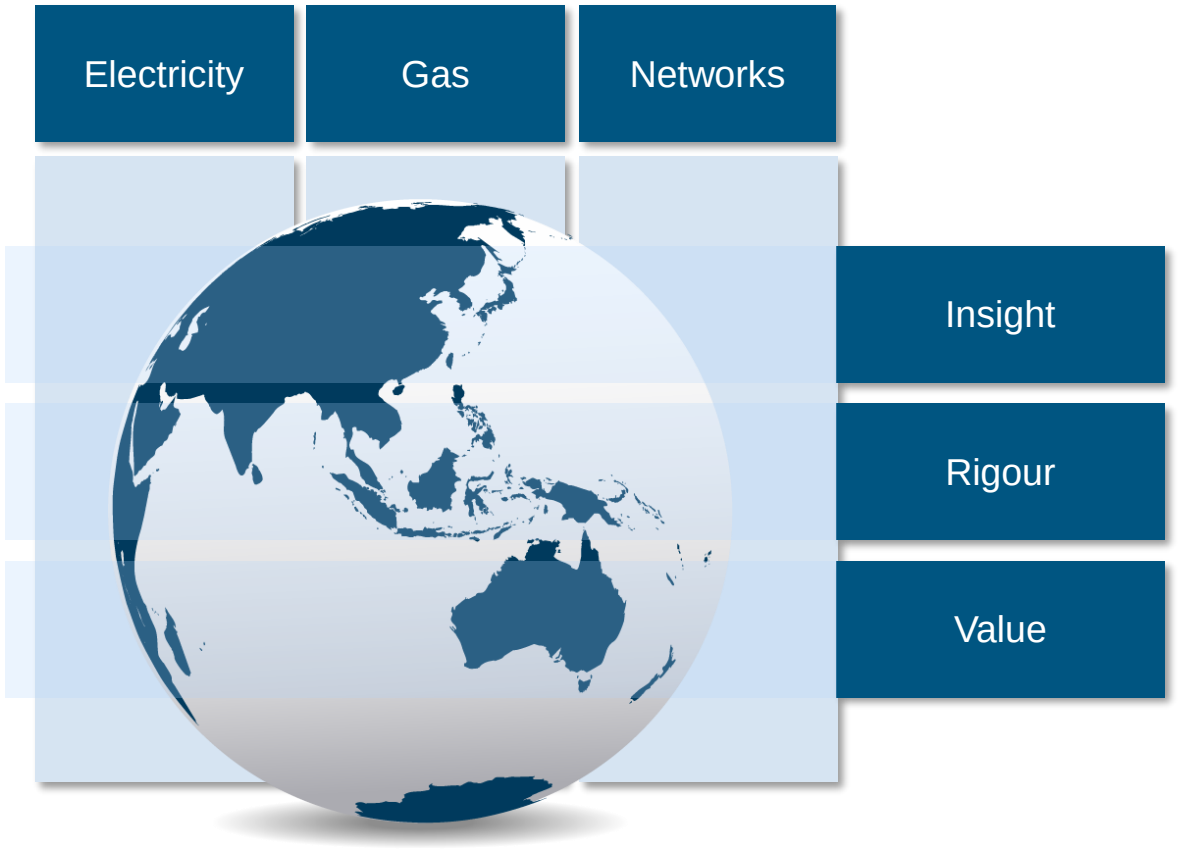
Thank You



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