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केन्द्रीय विद्युत प्राधिकरण
Central Electricity Authority
समन्वित संसाधन योजना प्रभाग
Integrated Resources Planning Division

New Delhi

Dated: 05th June 2024

विषय: - Study Report on “System Cost for drawing electricity generated by Renewable Energy”

Please find enclosed the Study Report on “System Cost for drawing electricity generated by Renewable Energy” carried out by CEA.

This issues with the approval of Chairperson, CEA.

This is for your kind information please.

(Apoorva Anand)
Deputy Director

Report on System Cost for drawing electricity generated by Renewable Energy

1.0 Introduction:

Hon'ble Minister (Power & NRE) in a meeting with Renewable Energy Implementing Agencies (REIAs) held on 27th and 28th March, 2024 directed CEA to carry out the following analysis.

Modelling for comparison of total cost to the country in case of:

- Setting up RE power projects in areas having high RE potential and then transporting the RE power to Areas having low RE potential

vis-à-vis

- Setting up RE power projects in areas having low RE potential and consuming the RE power locally in that area.

A study has been carried out by CEA to analyze the impact of transmission on landed cost of generation for Solar from different states as per the location specific profile. The aforesaid modelling study duly takes into account the factors like grid security and stability, interstate and intra state transmission charges and constraints

- 1.1 India has set a target of installing 500 GW of renewable energy (RE) capacity by 2030, so as to meet 50% of its total energy requirement from non-fossil fuel sources alone. This target is set as an action plan in combating climate change. As on 31st March 2024, the total installed RE capacity in the country is 190.572 GW, out of which the contribution of solar power is 81.813 GW, which is around 43%. Most of the RE capacity is in the renewable rich states of Rajasthan, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Maharashtra. Through the RPO mechanism, RE demand of non-RE rich States has also been met through adding RE generation in RE rich states as the higher Capacity Utilization Factor (CUF) leads to lower per unit generation costs. This has been aided by the waiver of ISTS transmission charges by the Central Government.
- 1.2 With increasing RE investments in naturally endowed States, the RE energy generated within the RE rich state cannot be absorbed fully by the state due to demand saturation of the RE state and the generation from these RE generators during high generation hours need to be transmitted in distant load centers of non-RE rich states through transmission infrastructure.
- 1.3 Transmission system provides service of Inter-connection between the source and consumption (load centers) of electricity. In Indian context, the transmission system is

broadly categorized as Inter-State Transmission System (ISTS) and Intra-State Transmission System (Intra-STs). RE generating stations are generally located far-off from load centers. Previously, these stations are connected with the grid normally at Intra-STs level and then to ISTS level. However, as large size generating stations are installing at RE rich states, they are directly connected at ISTS level. Therefore, the system cost for drawl of RE power for DISCOM will not only include cost of RE generation, but it will also include transmission charges at ISTS and Intra-STs level, as applicable.

- 1.4 In this report, we are examining the system cost incurred by beneficiaries while drawing RE power either from RE Generation connected at ISTS or In-STs. Even within the ISTS, the report also examined incremental transmission cost incurred for transmitting the RE energy, when more and more RE Generation is planned in a particular RE rich area.

2.0 Cost of generation from Vanilla Solar Projects

2.1 Typical cost of generation from Vanilla Solar Projects in different States:

	Specific Photovoltaic Power Output (kwh/kW) #	CUF (\$)	Levelized Tariff (Rs/unit) &
Rajasthan (Bhadla)	1750.2	0.28	2.66
Gujarat (Khavda)	1707.8	0.27	2.76
Maharashtra (Solapur)	1592.4	0.25	2.98
Uttar Pradesh (Bundelkhand)	1540.6	0.25	2.98
Assam (Sonit Pur)	1356.8	0.22	3.39

As per Global Solar Atlas Data,

\$ CUF computed after accounting for 1.4 AC/DC ratio

& Levelized tariff computed considering project cost of ₹4.5crore/MW, **80: 20 as Debt**: Equity, 12% RoE (post-tax), 10.45% interest rate, 25 years project life, 1% of Project cost as O&M with 4% annual escalation, depreciation for initial 15 years @ 4.67% and @2% for balance 10 years, and discount rate @8.61%

2.2 Recent discovered tariff for Vanilla Solar Projects connected at ISTS

Bidding Agency	Product	Bid conclusion	Total bid quantum	Discovered tariff (Rs/unit)
SECI	Tranche XIV Solar	Mar-24	1500 MW	2.56-2.57
NTPC	Solar	Jan-24	1500 MW	2.60-2.65

Note: Bids were not location specific and bids quoted by developers considering development of solar generation in high insolation areas

2.3 Recent discovered tariff for Vanilla Solar Projects connected at intra-State

State	Agency	Tendered capacity (MW)	Result date	Discovered Tariff (INR/kWh)
Maharashtra	MSAPL	207	11-Mar-2024	3.10
Gujarat	GUVNL	1,125	02-Mar-2024	2.62-2.67
Tamil Nadu	TANGEDCO	420	18-Nov-2023	3.28
Assam	APDCL	200	29-Aug-2023	3.90
Punjab	PSPCL	200	25-Jul-2023	2.75
Kerala	KSEB	40	07-Apr-2022	3.50

Uttar Pradesh	UPNEDA	200	12-Jan-2022	2.98
Bihar	BREDA	250	14-Aug-2021	3.11

The above bided tariffs are at minor variance from the costs calculated in para 2.1 which may be due to differences in financing, land costs, variations in CUF based on exact location, transportation costs, available expertise, etc.

3.0 Transmission Charges in the country

3.1 ISTS charges

ISTS charges for states as given below are taken from NLDC data.

States	In Rs/unit	
	2023-24	2024-25
Andhra Pradesh	0.51	0.52
Arunachal Pradesh	1.06	1.08
Assam	0.59	0.60
Bihar	0.56	0.57
Chandigarh	0.70	0.71
Chhattisgarh	0.58	0.59
Delhi	0.60	0.61
DNH & DD	0.62	0.64
Goa	0.56	0.57
Gujarat	0.60	0.61
Haryana	0.50	0.51
Himachal Pradesh	0.60	0.61
Jammu & Kashmir	0.72	0.73
Jharkhand	0.42	0.43
Karnataka	0.94	0.96
Kerala	0.68	0.70
Madhya Pradesh	0.64	0.66
Maharashtra	0.52	0.53
Manipur	0.79	0.80
Meghalaya	0.92	0.94
Mizoram	1.04	1.06
Nagaland	1.03	1.06
Orissa	0.60	0.61
Puducherry	0.79	0.80
Punjab	0.59	0.61
Rajasthan	0.64	0.66
Sikkim	0.75	0.76
Tamil Nadu	0.74	0.75
Telangana	0.61	0.63
Tripura	0.74	0.75
Uttar Pradesh	0.65	0.67

Uttrakhand	0.70	0.71
West Bengal	0.61	0.62
All India	0.63	0.65

3.2 Intra-State Transmission Charges

Intra-State transmission charges are taken from the report on “Key Regulatory Parameters of Power Utilities” as on 31.12.2023 issued by REC

In Rs/unit	
States	2023-24
Andhra Pradesh	0.26
Arunachal Pradesh	0.10
Assam	0.57
Bihar	0.21
Chhattisgarh	0.36
DNH & DD	0.03
Gujarat	0.38
Haryana	0.41
Himachal Pradesh	0.07
Jammu & Kashmir	0.68
Jharkhand	0.34
Karnataka	0.23
Kerala	0.44
Madhya Pradesh	0.12
Maharashtra	0.36
Manipur	0.45
Meghalaya	0.74
Orissa	0.24
Punjab	0.23
Rajasthan	0.37
Tamil Nadu	0.22
Telangana	0.20
Tripura	0.20
Uttar Pradesh	0.26
Uttrakhand	0.16
West Bengal	0.24

4.0 System cost for drawing solar generation at ISTS level vis-à-vis at Intra-STS level

4.1 In order to promote Renewable Energy, Ministry of Power has provided ISTS charges waiver for drawl of RE power and the waiver is likely to be phased out in graded manner from June 2025.

4.2 As beneficiaries of RE power do not have to pay any ISTS charges/losses, the cost impact of laying of transmission lines for transmitting the RE power is not considered during planning of RE generation. In this section, we have carried out an analysis to compare the system cost (generation cost +transmission charge) incurred by a beneficiary for drawl of power from a Solar Generator connected at ISTS level without any ISTS waiver vis-à-vis the system cost incurred by beneficiary for drawl of power from a Solar Generator connected at its intra-State level.

4.3 Assumptions for the study:

- i. The states considered for drawing RE power are Maharashtra, Tamil Nadu, Assam, Punjab, Kerala, Uttar Pradesh & Bihar.
- ii. The tariff for plain vanilla solar project discovered through competitive bidding by SECI for Tranche XIV (Bid concluded on Mar 2024) is in the range of 2.56 - 2.57 Rs/Unit Bids are not location specific and it is assumed (with high confidence) that bids developers will install the projects at high insolation areas. Based on this, a tariff of Rs 2.57/Unit is assumed.
- iii. Based on Transmission charges notified by Grid India for designated ISTS customers and based on GNA quantum, the ISTS charges for the year 2023-24 is calculated in Rs/kWh.
- iv. ISTS losses is considered as 4%.
- v. Intra-state transmission charges & losses as mentioned in Report on performance of state power utilities for the year 2023-24 is considered.

4.4 Approach for the study:

- i. It is assumed that solar plant is located in RE-rich state and utility is located in another state and drawing power from ISTS and Intra-state network. The landed cost of plain vanilla solar includes ISTS charges & losses and Intra-state charges & losses.
- ii. It is compared with the solar plant located in the low CUF state and utility with in the state is drawing power from Intra-state network. The landed cost of solar power includes Intra-state charges & losses only. The tariff for plain vanilla solar at state level is considered based on the discovered price determined in the recent bids along with state-wise CUF.

4.5 Landed cost for drawing Solar Power from ISTS:

- a) The formula for the determination of landed cost at ISTS level of power is taken as follows:

$$= \text{Tariff at Generator end} + (1 - \text{ISTS Loss \%}) * \text{ISTS charges} + (1 - \text{ISTS loss\%}) * (1 - \text{In STS loss\%}) * \text{In STS charges}$$

- b) State-wise landed cost of solar drawn from ISTS:

Drawee state	Discovered Solar Tariff at ISTS level (Rs/unit)	ISTS Charges (Rs/unit)	ISTS Losses (%)	Intra State Trans Charges (Rs/unit)	Intra State Losses (%)	Landed Cost (Rs/unit)
Maharashtra	2.57	0.52	4%	0.36	3.18%	3.40
Tamil Nadu	2.57	0.74	4%	0.22	3.00%	3.49
Assam	2.57	0.59	4%	0.57	3.27%	3.67
Punjab	2.57	0.59	4%	0.23	2.42%	3.35
Kerala	2.57	0.68	4%	0.44	3.30%	3.63
Uttar Pradesh	2.57	0.65	4%	0.26	3.22%	3.44
Bihar	2.57	0.56	4%	0.21	3%	3.30

4.6 Landed cost for drawing Solar power from within the state:

- a) The formula for the determination of landed cost of power is as follows:

$$= \text{Tariff at Generator end} + (1 - \text{In STS loss\%}) * \text{In STS charges}$$

- b) State-wise landed cost of power drawn from Intra State System connected Solar Plants

Drawee state	Discovered Solar Tariff at In STS level (Rs/unit)	Intra State Trans Charges (Rs/unit)	Intra State Losses (%)	Landed Cost (Rs/unit)
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Maharashtra	3.10	0.36	3.18%	3.45
Tamil Nadu	3.28	0.22	3.00%	3.49
Assam	3.90	0.57	3.27%	3.45
Punjab	2.75	0.23	2.42%	2.97
Kerala	3.50	0.44	3.30%	3.93
Uttar Pradesh	2.98	0.26	3.22%	3.23
Bihar	3.11	0.21	3.00%	3.31

4.7 Comparison of landed cost of power:

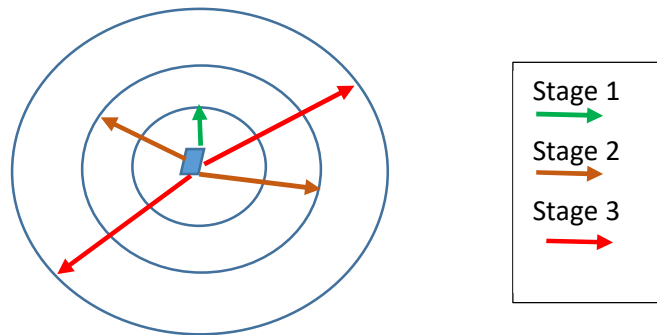
Drawee state	landed cost of power drawing at ISTS level (Rs/unit)	landed cost of power drawing within the state (Rs/unit)	Difference/ System Cost (in Rs/kWh)
Maharashtra	3.40	3.45	-0.04
Tamil Nadu	3.49	3.49	-0.01
Assam	3.67	3.45	-0.79
Punjab	3.35	2.97	0.38
Kerala	3.63	3.93	-0.29
Uttar Pradesh	3.44	3.23	0.20
Bihar	3.30	3.31	-0.01

It may be seen that though the cost of solar generation at ISTS level is cheaper compared to cost of generation at In-STS level, landed cost of solar power for many States after accounting for transmission charge is equivalent or cheaper in case it is drawn from a solar generator connected at In-STS level compared to the same connected to ISTS level.

5.0 Incremental ISTS cost for evacuation of power from particular RE rich area:

5.1 Presently, RE developers and planners are targeting high potential RE areas. In this section, we will examine cost of putting up ISTS system for transmitting power from a particular RE rich area.

5.2 As more and more RE generating stations are added in the system in a given resource rich location, the transmission infrastructure costs in the early stages is lower due to local consumption and margins in existing transmission corridors. However, with steady increase in generation in the same location, the local demand is saturated and the margins in the transmission corridors is exhausted. Transmission strengthening is required to transfer the generation to the further off load centres. As further generation is added, the demand being saturated in the state and adjoining load centre of other states, the power will need to flow to farther load centres as per laws of physics which would entail higher transmission investment for the evacuating the same MW of power over larger distances. The same is pictorially given below.



5.3 It is evident that, adding more and more transmission system will increase the transmission charges for states.

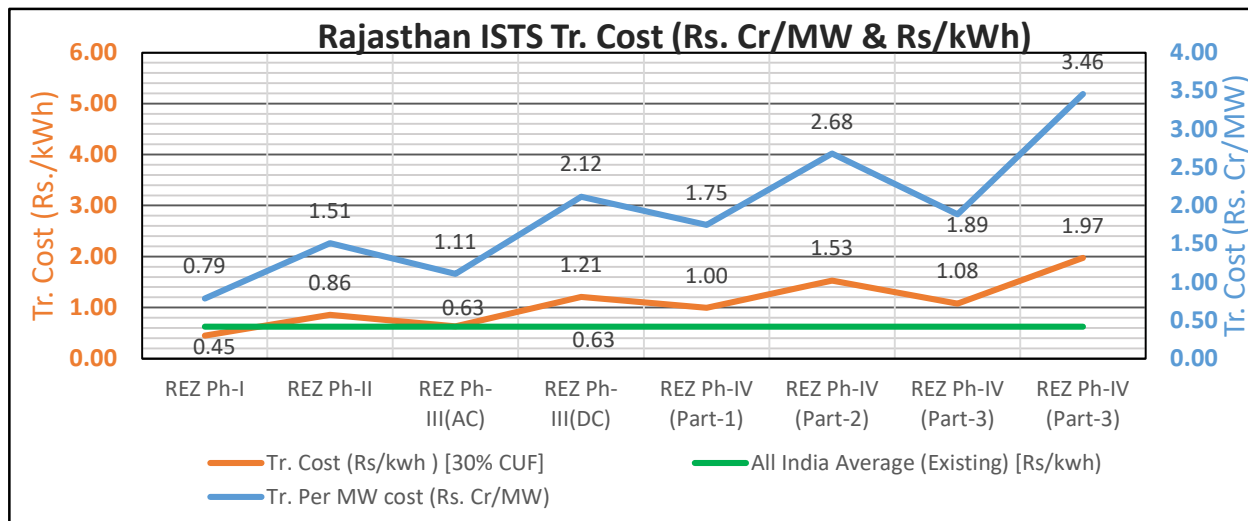
The incremental transmission cost for evacuation of Renewable Energy in Northern Region, Western region and Southern Region is described in subsequent sections.

5.4 Northern Region:

- i. In Northern Region, RE (solar) is coming in Rajasthan **in four contiguous districts of western Rajasthan viz. Jaisalmer, Jodhpur, Barmer & Bikaner** (94 GW out of 110 GW by 2030)
- ii. Initially AC corridors (68 GW) was planned in Rajasthan to all major load centres of neighbouring states (Haryana, Delhi, UP, Punjab, Madhya Pradesh etc.).
- iii. As seen from the table below, cost of AC corridors planned for evacuation of solar power from Rajasthan gradually increased from Rs. 0.45/unit to 1.97/unit.

Sl. No.	Transmission Scheme	Capacity (GW)	Estimated Cost (Rs. Cr.)	Tr. Per MW cost (Rs. Cr/MW)	Tr. Cost (Rs/kwh) [25% CUF]	Tr. Cost (Rs/kwh) [30% CUF]
1	Rajasthan REZ Phase-I(AC)	8.9	7000	0.79	0.54	0.45
2	Rajasthan REZ Phase-II(AC)	8.1	12200	1.51	1.03	0.86
3	Rajasthan REZ Phase-III(AC) [incl. Bhadla-III strengthening]	14	15492	1.11	0.76	0.63
4	Rajasthan REZ Phase-III(HVDC)	6	12700	2.12	1.45	1.21
5	Rajasthan REZ Phase-IV(Part-1) (Bikaner-II & Bikaner-III)(AC)	7.7	13460	1.75	1.20	1.00
6	Rajasthan REZ Phase-IV(Part-2) (Fat IV/Barmer-I)*(AC)	7.5	20081	2.68	1.83	1.53
7	Rajasthan REZ Phase-IV(Part-3) (Bikaner-IV)(AC)	6	11320	1.89	1.29	1.08
8	Rajasthan REZ Phase-IV(Part-4) (Fatehgarh/Barmer)(AC)	3.5	12101	3.46	2.37	1.97
		61.7	104354	1.69	1.16	0.97
	All India Average (Existing) [Rs/kwh]				0.63	

- iv. Further Evacuation corridors from these four districts need to be planned through HVDC system which provides controllability, reactive power support, stability to the grid and bulk power transfer over long distance. The cost of first HVDC link is about Rs. 1.21/unit.
- v. It can be seen from following graph that as we build more and more Solar Generator in particular area of Rajasthan, there is gradual increase transmission cost for evacuation of each MW and it has increased from Rs. 0.79 Cr/MW to Rs. 3.46 crore/MW.



5.5 Western Region:

- i. RE in WR is mainly concentrated in Gujarat (about 30GW in Khavda region only). The concentrated nature of above RE generation coupled with less demand in Northern Gujarat leads to gradual increase in the cost of the transmission.
- ii. As seen from following table, initially through AC system 22GW has been planned to be evacuated, the cost of which has gradually enhanced from Rs. 0.29/unit(Ph-I) to Rs. 1.55/unit (Ph-IV). Subsequently, 8.5 GW (Ph-V) has been planned to be evacuated through HVDC systems, the cost of which is about Rs. 2.66/unit. However, in the other locations of Gujarat and in MP and Maharashtra the cost remained low (Rs. 0.11/unit to Rs. 0.40/unit) due to distribution of RE generation.

Sl. No.	Transmission Scheme	State	Capacity (GW)	Estimated Cost (Rs. Cr.)	Tr. Per MW cost (Rs. Cr/MW)	Tr. Cost (Rs/kwh) [25% CUF]	Tr. Cost (Rs/kwh) [30% CUF]
1	Kallam (AC)	Maharashtra	3.25	635	0.20	0.13	0.11
2	Solapur (AC)	Maharashtra	1.5	471	0.31	0.22	0.18
3	Rajgarh/Neemuch(AC)	MP	3.5	1474	0.42	0.29	0.24
4	Chhatarpur (AC)	MP	1.5	239	0.16	0.11	0.09
5	Bhuj/Bhuj-II/Jam-Khambaliya/Lakadiya (AC)	Gujarat	12.5	8837	0.71	0.48	0.40
6	Khavda Phase-I(AC)	Gujarat	3	1544	0.51	0.35	0.29
7	Khavda Phase-II(AC)	Gujarat	5	5200	1.04	0.71	0.59
8	Khavda Phase-III(AC)	Gujarat	7	7829	1.12	0.77	0.64
9	Khavda Phase-IV(AC)	Gujarat	7	19016	2.72	1.86	1.55
10	Khavda Phase-V(HVDC)	Gujarat	8	37273	4.66	3.19	2.66
			52.25	82518	1.58	1.08	0.90
	All India Average (Existing) [Rs/kwh]					0.63	

- iii. It may be seen from following graph that as we build more and more RE in Khavda region (Gujarat), the cost of ac transmission system increases from Rs. 0.51/cr to Rs. 2.72 crore/MW. Subsequently, we also need to build HVDC system for evacuation of power to farthest point through HVDC system, for which transmission cost increases to Rs. 4.66 cr/MW

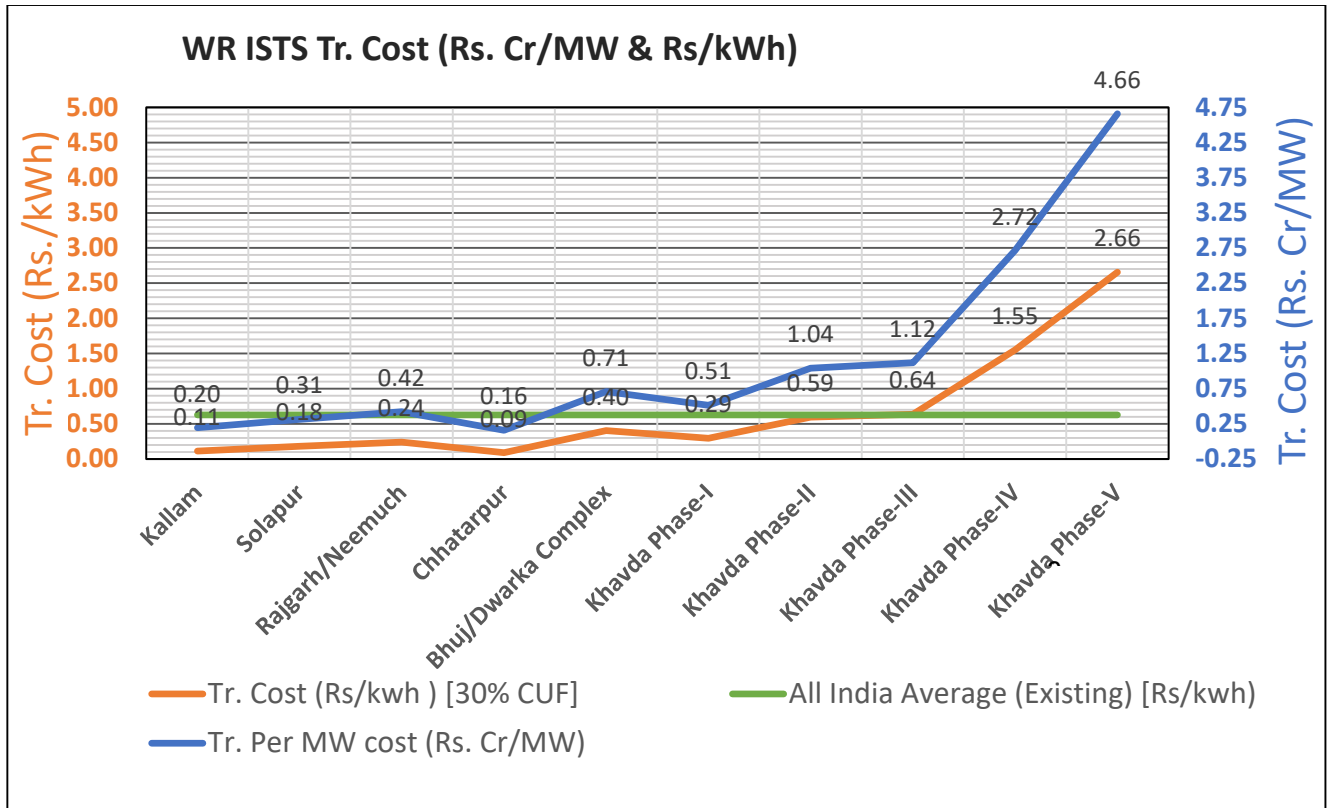


Fig (b): Transmission cost in Gujarat for different phases of Transmission Network

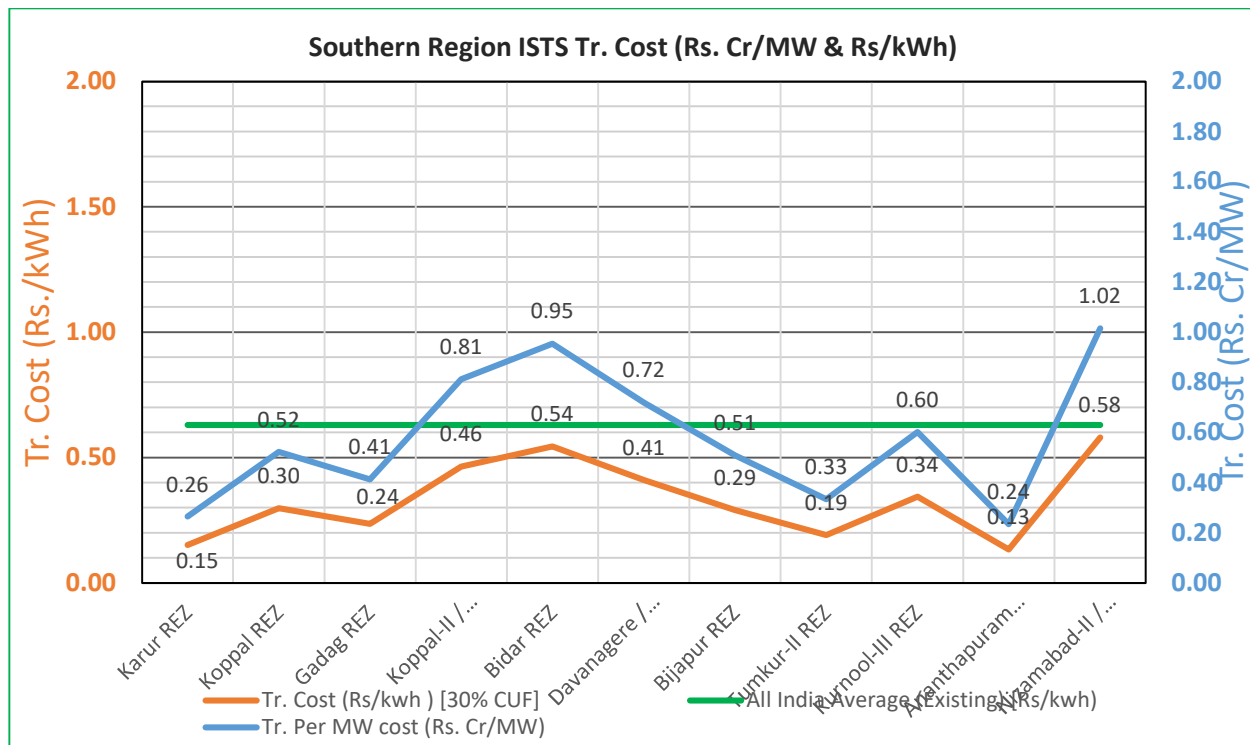
5.6 Southern Region

- The ISTS grid in Southern Region is well integrated among all the RE rich States of SR viz. AP, Karnataka, Tamil Nadu & Telangana. The load / demand points are spread across the states.
- The distributed nature of RE generation potential and loads in SR is leading to less transmission system requirement due to which the cost of the transmission system is also less (ranging from Rs 0.15/unit to Rs. 0.58/unit)

ISTS Transmission Schemes in Southern Region

Sl. No.	Transmission Scheme	State	Capacity (GW)	Estimated Cost (Rs. Cr.)	Tr. Per MW cost (Rs. Cr/MW)	Tr. Cost (Rs/kwh) [25% CUF]	Tr. Cost (Rs/kwh) [30% CUF]
1	Karur REZ	Tamil Nadu	1.5	396	0.26	0.18	0.15
2	Koppal REZ	Karnataka	2.5	1306	0.52	0.36	0.30
3	Gadag REZ	Karnataka	2.5	1033	0.41	0.28	0.24
4	Koppal-II / Gadag-II REZ	Karnataka	9	7308	0.81	0.56	0.46
5	Bidar REZ	Karnataka	2.5	2385	0.95	0.65	0.54
6	Davanagere / Bellary REZ	Karnataka	5.5	3953	0.72	0.49	0.41
7	Bijapur REZ	Karnataka	2	1016	0.51	0.35	0.29
8	Tumkur-II REZ	Karnataka	1.5	501	0.33	0.23	0.19
9	Kurnool-III REZ	Andhra Pradesh	4.5	2705	0.60	0.41	0.34
10	Ananthapuram REZ	Andhra Pradesh	3.5	823	0.24	0.16	0.13
11	Nizamabad-II / Medak / Rangareddy REZ	Telangana	6	6096	1.02	0.70	0.58
			41	27522	0.67	0.46	0.38
	All India Average (Existing) [Rs/kwh]					0.63	

- iii. Further, it can also be seen that cost of transmission system is also less than Rs 1 crore/MW.



5.7. Findings:

- Presently bids invited by REIA for setting up RE generation are not location specific and bidders go for high RE potential areas, without considering investment required in transmission
- Due to concentration of generation associated with less demand in that pocket, cost of evacuation of RE energy from high RE potential areas in Western Rajasthan (Jaisalmer, Jodhpur, Barmer & Bikaner) and Gujarat (Khavda) increasing day by day:
 - ✓ In Western Rajasthan, new transmission cost gradually increased from Rs. 0.45/unit to 1.97/unit.
 - ✓ In Khavda, new transmission cost gradually enhanced from Rs. 0.29/unit(Ph-I) to Rs. 1.55/unit (Ph-IV).
- Tentative cost for getting one unit of RE generation from high RE rich areas like Western Rajasthan and Khavda and relative less RE potential areas

	Generation Cost (Rs/unit)	ISTS Transmission Cost (Rs/unit)	Total (Rs/unit)
Jaisalmer, Raj (CUF:30%)	2.46	1.97	4.43
Khavda, Guj (CUF:29%)	2.54	1.55	4.09
Solapur, Mah (CUF:27%)	2.73	0.18	2.91
Bundelkhand, UP (CUF:26%)	2.84	0.67*	3.51
Assam (CUF:23%)	3.21	0.60*	3.81

6. Operational risks due to concentration of solar/RE generation at certain RE rich pockets

- A large number of generation loss events (~47 nos. events of >1000 MW generation loss between Jan 2022 to March 2024 at ISTS level) have already taken place in the large RE complexes (especially Rajasthan). The largest generation loss was of the order of ~7000 MW on 15th May 2023.
- In addition to the generation loss events, there has been generation reduction of ~8000 MW within 01 (one) hour due to cloud cover in Rajasthan on 28th May 2023.
- In case of large-scale renewable capacity in close vicinity, the possibility of losing a large chunk of generation (solar) due to any disturbance or large cloud cover also increases significantly.

- iv. Due to the above, the requirement of reserves (primary, secondary and tertiary) for handling contingencies will increase. These reserves need to be maintained in the interstate as well as intrastate generating stations.
- v. The increasing addition of RE plants (non-synchronous) in the grid is expected to reduce the system inertia which is inherently provided by synchronous generators. Synthetic inertia through fast frequency response would be required to address the higher rate of change of frequency during any load-generation imbalance.

7. Recommendations:

It may be seen that concentration of solar generation not only poses operational risk to Grid but also calls for extra investment in transmission evacuation infrastructure. It is suggested that SECI / REIAs may invite location specific bidding to optimize investment in required system cost for RE generation and encourage establishment of RE in a distributed manner-reduced risk associated with concentrated generation at a certain place.

States may also be encouraged to invite bids for location in their states. They may be told about indirect advantages such as local area development, employment generation etc.
