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Are pumped storage schemes beneficial for harnessing the Krishna river water further ?

The demand for water from the river Krishna surpasses the water available in the river. The 75% dependable water available in the river will be completely harnessed in next few years. Substantial quantity of water is available at 50% dependability over the water available at 75% dependability in the river. This conceptual paper examines the techno-economic feasibility of harnessing this unreliable water available during good monsoons for irrigation needs and power generation by pumped storage schemes.

Introduction

The river Krishna has drainage area of 2,58,948 sq.km of which 26.8% lies in Maharastra, 43.8% in Karnataka and 29.4% in Andhra Pradesh (AP). It has two major tributaries which are Tungabhadra and Bhima rivers. The Bhima joins Krishna just before entering into AP and Tungabhadra joins Krishna near Kurnool town (Fig.1) in AP. Krishna river after the confluence of Tungabhadra passes through a narrow gorge for a distance of 130 km in which two large reservoirs, Srisailam and Nagarjuna Sagar are located. These reservoirs create a hydraulic head of nearly 90 meters each, which have been harnessed for generating hydroelectric (HE) power.

Water availability

Being a peninsular river, most of the water flow in the river is during south west monsoon which lasts for about four months duration. A typical hydrograph of the river at Vijayawada during monsoon season is shown in Fig. 2. The water available in the river shoots up from negligible quantity in the middle of July and becomes negligible abruptly after the second week of November. The discharge in the river is negligible during rest of the year. The maximum discharge of this river is 33,810 cumecs (m^3/sec) and the minimum is less than 3 cumecs. The total annual mean runoff is 67,675 million cubic meters or 2390 thousand million cubic feet (TMC). The water run off in the river vary widely from year to year and month to month depending on the vagaries of the monsoon. It has been estimated that 75% dependable yield in the river is 2060 TMC and is allocated among the riparian states of Maharastra, Karnataka and AP by Bachavat Tribunal. However, AP is allowed to use the excess water available in the river during better monsoon periods up to the year 2000 AD when tribunal award will be reviewed. AP is already utilising its full share of water and trying to use the surplus water. Karnataka and Maharastra are making their full efforts to utilise their share of water by 2000 AD.

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Water requirement

The cultivable area and net sown area are 78% and 60% of the geographical area of the river basin respectively. The high percentage of sown area coupled with semiarid weather conditions in this river basin increases the water demand for irrigation needs. In addition the adjoining Pennar river basin which is perennially drought prone area with scanty rain fall, further raises the water demand for its irrigation needs from the Krishna river. Moreover, Krishna river has good potential for power generation which has been harnessed mostly by Koyna, Srisailam, Nagarjuna Sagar HE stations and few HE stations constructed by Tatas in private sector. The demand for water is unlimited from this river since generating HE power is highly profitable.

Needs for pumped storage reservoirs

The above factors necessitate to make use of the available water in the Krishna river to the maximum extent either for power generation or irrigation. More than 800 TMC of unreliable water is available at 50% dependability above 2060 TMC of 75% dependable water during good monsoon years. The quantum of water that had gone into sea from 1972 to 1992 is shown in Table 1. Substantial quantity of this water has overflowed downstream on the spillway of dams during floods without even being used for secondary power generation in the existing HE stations. Full utilisation can be achieved by creating large reservoirs to store flood water during good monsoon years which otherwise go waste into sea. This stored flood water can be put to use either for power generation or irrigation needs.

TABLE 1 WATER DRAINED INTO SEA

Monsoon year (June to May)	Water drained into sea (TMC)
1972-73	163
1973-74	1217
1974-75	978
1975-76	2592
1976-77	1039
1977-78	640
1978-79	1867
1979-80	855
1980-81	1068
1981-82	1239
1982-83	456
1983-84	1481
1984-85	332
1985-86	157
1986-87	136
1987-88	Not Available.
1988-89	1244
1989-90	Not Available.
1990-91	1045
1991-92	1204
1992-93	323

Nearly 1400 TMC of storage capacity is already created or in advanced stage of creation till now. It would be difficult to identify further new storage reservoirs on the main river with less submergence area. However storage capacity can be created on the minor/medium tributary rivers which are directly emptying into the existing storage reservoirs such as Srisailam, Jurala, Nagarjuna Sagar, etc., by envisaging pumped storage schemes (PSS).

A typical PSS consists of an upper reservoir, HE power station and a downstream reservoir. The HE power station has an additional feature of reversible turbine capability (i.e. turbines can be used as pumps to lift water to higher level by consuming electricity). When water is available, this HE station pumps water into upper reservoir from the downstream reservoir and stores for future uses. This stored water is released through HE turbines into downstream reservoir, generating electricity whenever required.

These proposed PSS pump water from the existing storage reservoir (downstream reservoir) located on the main river into an upper storage reservoir located on its tributary during monsoon season. This water is released into the downstream reservoir during non monsoon season for further power generation in the down stream HE power stations and/or irrigation needs.

Advantage of PSS

The advantages of PSS which make it multi-purpose and economically viable are given below:

1. It stores flood water to utilise during bad monsoon years.
2. It consumes the surplus power during monsoon season preventing thermal power stations from backing down because of secondary power availability from HE Stations.
3. Cheap imported power from adjacent Regional Electricity Boards or State Electricity Boards can be used for pumping requirements during monsoon season.
4. It can also be used as a truly peaking power station to meet daily as well as seasonal peak demands.
5. It generates more power than what it consumes provided HE stations with fairly good hydraulic head are located downstream on the river.
6. The stored water can be used for creating irrigation facilities and/or drinking water requirements.
7. This stored water can be utilised to control the salinity ingress in estuaries and to maintain the river regime after using for power generation. Bachavat Award has not allocated water out of 75% dependable yield of Krishna river for this purpose. However, the recent opinion of experts is that ten (10%) percent of 75% dependable water of major rivers shall be spared for this purpose.

Suitable location of PSS

Some of the suitable sites for locating these PSS can be explored upstream of Srisailam reservoir on the medium/minor rivers which are directly emptying into it because of the following advantages.

1. Most of the flood water during good monsoon years passes through this dam since the river at this point covers 80% of the total catchment area.
2. Being a large reservoir of capacity nearly 200 TMC, it can retain the peak flood water and make available to the PSS over a period of time to pump into the upper reservoir.
3. Fairly good hydraulic head (90 to 210 metres) is available to generate additional hydro power by using this surplus water before putting to irrigation uses. This aspect makes the PSS economically viable because it allows to generate more power with the stored flood water than the power consumed to pump into the storage reservoir.
4. Srisailam HE station has 770 MW under operation and another 900 MW is under advanced stage of construction. This peaking HE station would make available secondary power during monsoon period to nearby PSS which reduces transmission lines cost and transmission losses.
5. The water stored by the PSS can be used as carry forward storage to advance the sowing activity in the Krishna Delta, Nagarjuna Sagar command area and

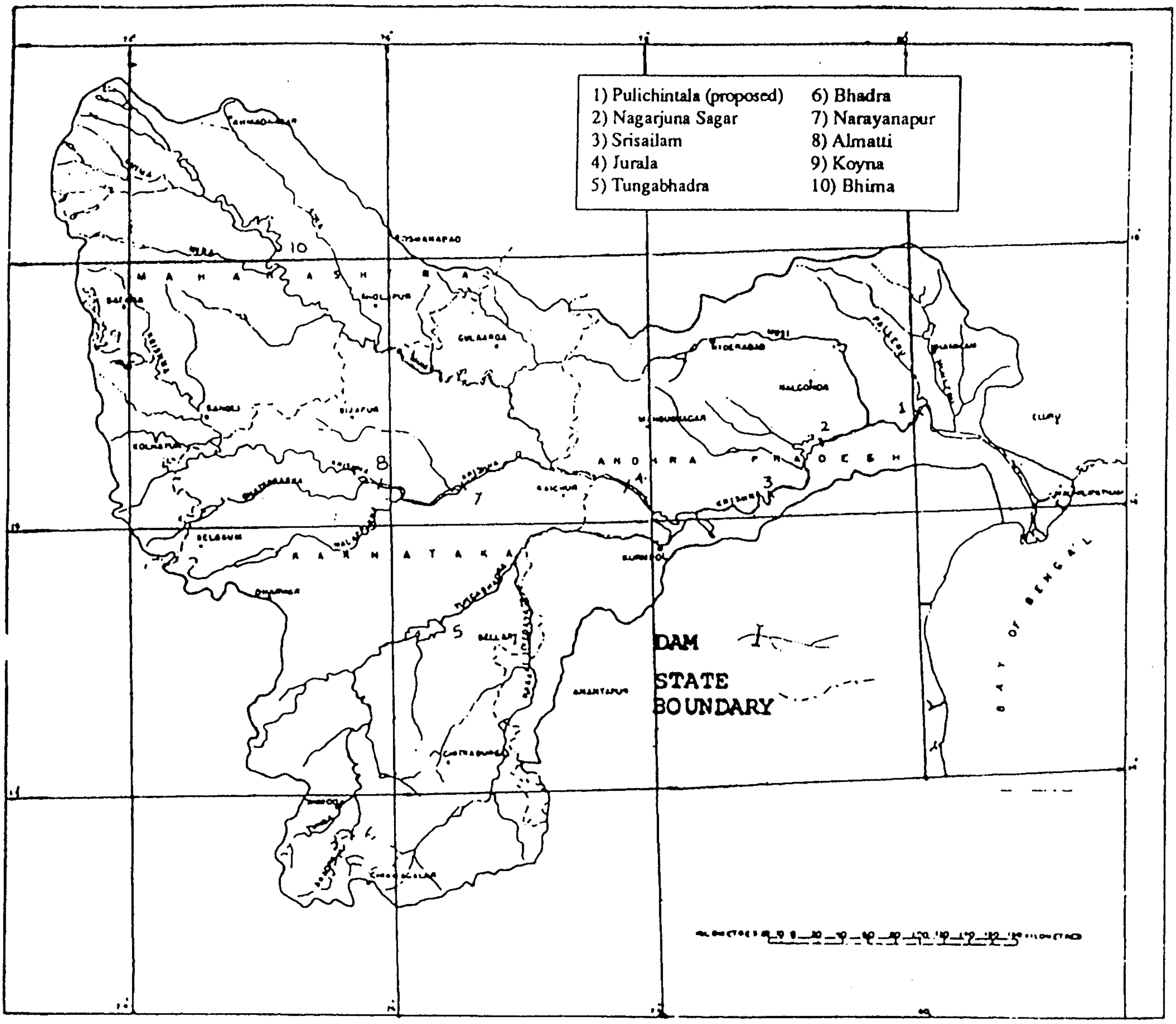

Fig.1 Basin plan of the river Krishna

Srisailam command area, to match with the onset of monsoon without waiting for sufficient inflows into the Nagarjuna Sagar and Srisailam reservoirs. In this way it would be beneficial to grow long duration or multiple irrigated crops. So the water stored by the PSS gives enormous flexibility in the better management of available water to maximise the benefits to irrigation and power generation.

6. Many irrigation schemes are under construction or contemplation drawing water from Srisailam reservoir such as Srisailam Right Bank Canal, Hindri-Neeva, Telugu Ganga, Velugodu, Galeru Nagari, K.C. Canal remodelling, Srisailam left Bank Canal, etc. These schemes envisage storing required water in balancing reservoirs. These reservoirs will receive water through flood canals from the Srisailam reservoir when flood water is available. The PSS option is better alternative to 'balancing reservoirs with associated flood canals' since it can supply water to these irrigation schemes throughout the cropping season by releasing water into Srisailam reservoir. The canals of irrigation schemes can be just sized to supply the water throughout the irrigation period from Srisailam reservoir. There will be substantial reduction in the cost of these irrigation schemes by avoiding the expenditure on balancing reservoirs and flood canals due to PSS.

CASE STUDIES:

In case, a storage reservoir of live capacity 318 TMC along with a pumped storage HE Station is to be created on a medium/minor river which is emptying directly into Srisailam reservoir, this reservoir acts as upper reservoir for

TABLE 2 BENEFITS FROM THE PSS IN VARIOUS COMBINATIONS OF MONSOON BEHAVIOR

Successive two monsoons behaviour.	Availability of carry forward storage from previous year.	Water supply to irrigation systems downstream of Srisailam Dam.	Water supply to irrigation systems from Srisailam reservoir.	Creation of carry forward storage for next year.
GB	YES	YES*	YES	NO
BG	NO	YES	YES	YES
BB	NO	YES#	NO	NO
GG	YES	YES*	YES	YES

B -> Bad monsoon year. G -> Good monsoon year.
* Cropping\Sowing activity starts with the onset of monsoon (June 1st). Otherwise it starts in the middle of July month.
# Existing old irrigation schemes will be given priority in supply of available waater.

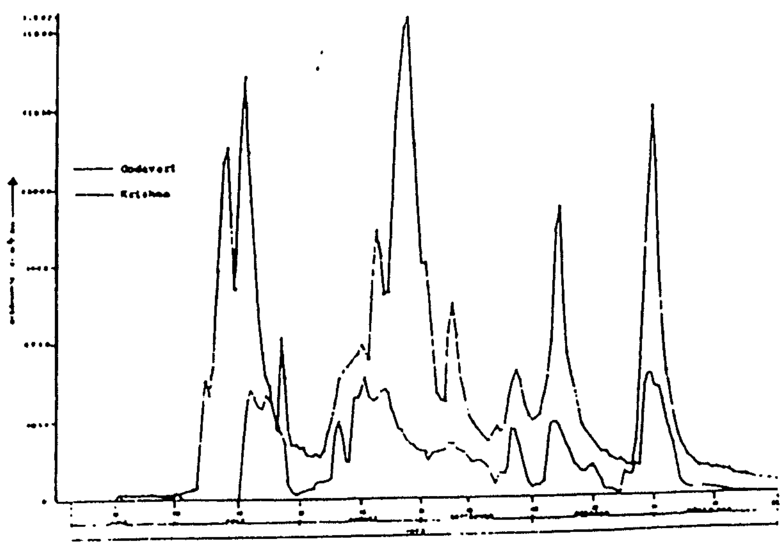

Fig.2 Hydro graph of Krishna and Godavari rivers in 1973 monsoon period

the pumped storage HE station and Srisailam reservoir acts as its downstream reservoir. When the flood water is available in the Srisailam reservoir, water is pumped into the upper reservoir by operating the HE turbines in pumping mode. This stored water is released into Srisailam reservoir by operating HE turbines in turbine mode whenever required to meet irrigation and/or power generation needs

It is assumed that flood water can be pumped into upper reservoir for 90 days (2160 hours) at the rate of 1157.4 cumecs from the Srisailam reservoir during good monsoon season. The evaporation and seepage losses in the upper reservoir is assumed equal to inflows from its catchment area.

The following two cases are examined for which this stored water can be put to use:

1. Case I: The water is used for power generation in the Srisailam HE station (90 meters head), Nagarjuna Sagar dam HE station (90 meters head) and proposed Pulichintala HE station (30 meters head) before letting into sea without any irrigation usage. So 210 meters total hydraulic head is available in the down stream of PSS for power generation.
2. Case 2 : At present sufficient inflow into the Nagarjuna Sagar and Srisailam reservoirs is not taking place till the later half of July month compelling farmers to start sowing activity in the second half of July month every year. It is proposed to use the stored water by the PSS for irrigation in Krishna Delta, Nagarjuna Sagar command and Pulichintala command (proposed) before sufficient inflow takes place in the reservoirs by advancing the crop sowing activity to match with the onset of monsoon (i.e. June Ist).When the proposed Pulichintala reservoir along with HE station is constructed, it can supply water to some of the existing irrigated area in Nagarjuna Sagar command. This would facilitate to extend the Nagarjuna Sagar Right Bank Canal up to Somasila reservoir in Pennar river basin bringing additional area under irrigation and to transfer Krishna water to Pennar river basin for its irrigation requirements. When this carry forward storage water is used in the downstream irrigation requirements, the water available upstream in Srisailam reservoir can be used for creating additional irrigated area under Telugu Ganga, Galeru-Nagari, Velugodu, Hindri Neeva, Srisailam Left Bank Canal, etc. schemes. It is considered that 30%, 20% and 50% of the 318 TMC of carry forward storage water is used for irrigation in Krishna Delta, Pulichintala command and Nagarjuna Sagar command respectively. Nearly 210 meters,180 meters and 90 meters hydraulic heads are available in the downstream HE stations for power generation before using for irrigation from Krishna Barrage, Pulichintala reservoir and Nagarjuna Sagar reservoir respectively. The average head available is 144 meters (210 x 0.3 + 180 x 0.2 + 90 x 0.5) for power generation before using for irrigation during good monsoon years.

WATER MANAGEMENT

It is envisaged that the water stored in the PSS is let into downstream reservoirs (Srisailam and Nagarjuna Sagar) before the end of every monsoon year. These downstream reservoirs being partially empty during the later half of monsoon year, retain the water as carry forward storage for the next monsoon year. This will facilitate to generate power from the stored water in the PSS during summer months when the power/energy shortage is more acute and downstream HE stations are not in operation due to lack of water.

When water availability in the downstream (Srisailam, Nagarjuna Sagar, etc.) reservoirs is sufficient during good monsoon years, water requirement for all the irrigation systems can be met from the downstream reservoirs itself without depending on the water stored in the PSS. The stored water in the PSS during good monsoon years is used as carry forward storage for next year.

TABLE 3 ECONOMIC ANALYSIS OF PUMPED STORAGE SCHEME (CASE-I)

Average head of pumped storage scheme, (meters)	Pumped storage scheme capacity (MW)		Gross power generation capacity (MW) with downstream head (1934 MW)	Energy generation (million kWh)			Revenue (Rs. crores per year)			Economically affordable investment	
	Pump mode	Turbine mode		Gross generation	Consumption (pump mode)	Net generation	Energy sales	Energy purchases	Net revenue	Rs. crores	Rs.crores /MW (turbine mode)
30	406	294	2228	2406	438	1968	722	31	691	3455	11.75
40	542	391	2325	2511	585	1926	753	41	712	3560	9.10
50	677	489	2423	2617	731	1886	785	51	734	3670	7.51
60	813	587	2521	2723	878	1845	817	61	756	3780	6.44
70	948	685	2619	2829	1024	1805	849	72	777	3885	5.67
80	1084	783	2717	2934	1171	1763	880	82	798	3990	5.10
90	1219	881	2815	3040	1317	1723	912	92	820	4100	4.65
100	1354	979	2913	3146	1462	1684	944	102	842	4210	4.30
110	1490	1076	3010	3251	1609	1642	975	113	862	4310	4.01

Notes :

1. Overall effeciency in turbine mode and pump mode is 85% each. Average pumping and generating hours each are 1080 hours in a year for economic analysis.
2. Energy purchase price is at Rs 0.70 per kWh during good monsoon years. Energy sale price is at Rs.3.0 per kWh.
3. Financial cost (interest on loan capital, return on equity capital and depreciation) is 19% of PSS cost. O&M cost of PSS is 1% of its cost.
4. The affordable investment also includes rehabilitation compensation, interest during construction. price escalation during construction, etc.

TABLE 4 ECONOMIC ANALYSIS OF PUMPED STORAGE SCHEME (CASE-II)

Average head of pumped storage scheme, (meters)	Pumped storage scheme capacity (MW)		Gross power generation capacity (MW) with downstream head (1326 MW)	Energy generation (million kWh)			Revenue (Rs. crores per year)			Economically affordable investment	
	Pump mode	Turbine mode		Gross generation	Consumption (pump mode)	Net generation	Energy sales	Energy purchases	Net revenue	Rs. crores	Rs.crores /MW (turbine mode)
30	406	294	1620	1750	438	1312	525	31	494	2470	8.40
40	542	391	1717	1854	585	1269	556	41	515	2575	6.59
50	677	489	1815	1960	731	1229	588	51	537	2685	5.49
60	813	587	1913	2066	878	1188	620	61	559	2795	4.76
70	948	685	2011	2172	1024	1148	637	72	565	2825	4.12
80	1084	783	2109	2278	1171	1107	683	82	601	3005	3.84
90	1219	881	2207	2384	1317	1067	715	92	623	3115	3.54
100	1354	979	2305	2489	1462	1027	747	102	645	3225	3.29
110	1490	1076	2402	2594	1609	985	778	113	665	3325	3.09

Notes :

1. Overall effeciency in turbine mode and pump mode is 85% each. Average pumping and generating hours each are 1080 hours in a year for economic analysis.
2. Energy purchase price is at Rs. 0.70 per kWh during good monsoon years. Energy sale price is at Rs.3.0 per kWh.
3. Financial cost (interest on loan capital, return on equity capital and depreciation) is 19% of PSS cost. O&M cost of PSS is 1% of its cost.
4. The afrordable investment also includes rehabilitation, compensation, interest during construction, price escalation during construction, etc.

The following possibilities are examined for planning usage of water with the help of PSS :

1. Bad monsoon succeeds good monsoon (GB): The carry forward storage in the downstream reservoirs will be utilised for early crop up to middle of July month in the command areas of Krishna Barrage, Pulichintala and Nagarjuna Sagar. The fresh inflow into downstream reservoirs from later half of July month, will be used for rest of irrigation needs of these areas and irrigation needs of Srisailam command area. In this case entire irrigation needs are met and creation of carry forward storage for next year is not possible due to bad monsoon year.
2. Good monsoon succeeds bad monsoon (BG): Since the carry forward storage could not be maintained in the previous year, there is no water available to start sowing activity with the onset of monsoon. Water will be supplied to the entire irrigated area under all reservoirs from 15th July when the inflow into the reservoirs is adequate for irrigation needs. Being a good monsoon, surplus water is available to pump into the PSS to create carry forward storage for next year. Pumping operation of PSS is done with the secondary power available from the HE stations during monsoon season.
3. Bad monsoon succeeds bad monsoon (BB): In this case sufficient water is not available in the river due to bad monsoon and absence of carry forward storage from previous year. Priority is given to supply water to the old irrigation systems due to insufficient water availability and pumping operation also can not be done for creating carry forward storage. The probability of two successive bad monsoons is once in four years when bad monsoon occurrence is once in two years.
4. Good monsoon succeeds good monsoon (GG): The carry forward storage in the downstream reservoirs is used for early crop up to middle of July in the command areas of Nagarjuna Sagar, Pulichintala and Krishna Barrage. The fresh inflow after 15th July into the downstream reservoirs during the good monsoon will be used for the rest of irrigation needs of these areas and irrigation needs of Srisailam command area. When flood water is available, water is pumped into the PSS by consuming secondary power from HE stations to create carry forward storage for next year.

As explained above, the dependability of water for newly irrigated areas due to the PSS, is three years out of four years which is 75% dependability. Water availability is not possible from second bad monsoon year when bad monsoons occur successively. The benefits of PSS during various combinations of monsoon behaviour (good or bad) is shown in Table 2. PSS facilitates to harness the water for irrigation twice its storage capacity (upper reservoir) during good monsoon years by creating carry forward storage for next year.

Economic analysis

Average pumping/generating hours of PSS: The PSS would be in operation when water availability in the river is nearly at 50% dependability. During good monsoon year, the PSS pumps water for 90 days (2160 hours). The probability of good monsoon at 50% dependable yield is once in two years. So the operating hours of PSS both in pumping mode and turbine mode are considered as 1080 hours/year each for economic analysis purpose.

Power purchase price: During good monsoons, unexpected cheap secondary power from the HE stations is available. If the power demand could not consume the available secondary power from the HE stations, few thermal power stations need to be taken out of operation. Pumping operation of PSS would consume this secondary power facilitating thermal power stations keep operating. The incremental cost for enhanced power generation by the thermal stations is its fuel cost only. So the power purchase price of PSS is considered as Rs. 0.70 per kWh which is average fuel cost of thermal station.

Power sale price : The generation cost of latest thermal power stations which are meant for catering to base load, is nearly Rs. 2.5 per kWh. Moreover the hydro power generated due to PSS is peaking power which can meet daily peak demands as well as seasonal energy shortages. So the sale price of power generated due to PSS is considered as Rs. 3 per kWh.

The following are the major features of a PSS which influences its installation cost/MW :

1. Hydraulic head of the turbines: If head of turbines increases, the equipment cost per MW decreases.
2. Height of dam: If the dam height is more, its cost increases.
3. Submergence area of reservoir: If the submergence area is more due to shallow storage capacity, the cost of land acquisition, compensation and rehabilitation expenditure increases.

So it is not possible to estimate the cost of the PSS without site specific data. In the absence of site specific data, an attempt is made to find the economically affordable investment per MW (turbine mode) for various average hydraulic heads of PSS.

The following pattern of using the stored water in the PSS is considered for economic analysis:

Case I : The stored water (318 TMC) is entirely used for power generation during good monsoon years which take place one out of two (50%) years. So 210 meters total hydraulic head is available in the downstream of PSS which is equal to 1934 MW power generation capacity. From the economic analysis shown in Table 3, the econmically affordable cost per MW (Rs. 4.01crores/MW) of PSS is very favourable up to 110 meters average hydraulic head.

Case II: The carry forward storage water (318 TMC) is used for power generation in the downstream HE stations before using for irrigation needs. The available head in the downstream of PSS is 144 meters which is equal to 1326 MW power generation capacity. From the economic analysis shown in Table 4, the economically affordable cost per MW (Rs. 3.54 crores/MW) of PSS is very favourable up to 90 meters average hydraulic head. If the stored water is to be used for irrigation finally as explained and the average hydraulic head of the PSS is less than 90 meters, the PSS is economically viable by the revenue from its power generation alone without expecting any revenue from irrigation usage.

Other beneficial features of PSS: The dam of the PSS can be non overflow type without any spillway because the peak flood flows from its catchment area is fraction of the storage reservoir capacity envisaged. The hydro turbines of PSS can easily handle the flood water to pass downstream in case it is necessary. This feature tends to reduce the cost of PSS.

The dead storage of the reservoir created by PSS can be nominal since the inflows carrying silt from its catchment area is negligible. This feature is one of the factors to maximise the live storage capacity of PSS.

Transfer of Godavari river water to Krishna river

Godavari river has substantial water flow from July to November and negligible flow in rest of months. Typical hydrograph of the river during monsoon season is shown in Fig. 2. This necessitates to construct storage reservoirs on the river to utilise water during lean flow period for irrigation needs in its basin and to transfer to river Krishna. Already our irrigation planners have proposed to transfer Godavari water to Krishna river by identifying multi purpose dams at Inchampally and Polavaram as diversion points. These are interstate projects which would submerge vast area of thick reserve forests and necessitate rehabilitation of effected tribal population posing difficulty in getting environment clearances. It is required to reduce the proposed storage capacities drastically to minimise interstate, forest submergence and tribal population rehabilitation problems. These reduced storage capacities would be sufficient only to the water requirements of identified irrigation schemes directly under these reservoirs leaving no scope to transfer water to Krishna river during lean flow period.

Godavari river flood water can be diverted to Krishna river during monsoon months by gravity to Krishna Barrage and Pulichintala reservoir to make up shortage of water during bad monsoons. This can be achieved without any storage reservoirs on Godavari river for this purpose. This would facilitate to create carry forward storage by pumping water available in the upstream of river at Srisailam reservoir into PSS even during bad monsoons. Thus the dependability of water for various requirements from Krishna river can be enhanced to 100% ultimately by transferring Godavari water to Krishna during monsoon months only. In this way, the storage capacity of the PSS obviates to some extent the need of storage reservoirs on Godavari to transfer water to Krishna river

Conclusion

Envisaging few pumped storage schemes to harness the 50% dependable water in the river Krishna is economically viable by the revenue from its power generation alone without expecting any revenue from irrigation usage. The PSS has high flexibility to meet any or combination of the following needs:

Power generation :

1. Power generation to meet daily peak demand.
2. Power generation to meet seasonal (summer) shortages.
3. To store the surplus power in the grid and supply to grid during shortage.
4. To consume the surplus power available in the grid during good monsoon seasons.

Irrigation uses :

1. To convert 50% dependable yield into 75% dependable yield for creating new irrigation facilities.
2. To supply additional water to the existing irrigation facilities.
3. To maintain optimum water levels in downstream reservoirs for feeding various irrigation canals for longer duration.
4. To match the cropping/sowing activity with the onset of monsoon by maintaining carry forward storage.
5. To act as substitute to the balancing reservoirs of new irrigation schemes and storage reservoirs on Godavari river also.

Water uses from the PSS can also be altered in future to match the changing needs. The water available between 50% and 75% dependable yield in the river can be harnessed economically for creating new irrigation facilities with assured water availability for three (3) out of four (4) years by envisaging few PSS.

The water demand from the Krishna river surpasses the water available in the river. Already, most of the reliable water in the river has been harnessed. The next step would be to harness the unreliable water available in the river. This can be achieved economically by envisaging few pumped storage schemes located upstream of the existing reservoirs. Ultimately Godavari water can be transferred to Krishna river for further stabilisation of irrigation in Krishna and Pennar river basins.

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