Optimizing Agricultural to Hydro power water transfer

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Abstract. Hydro energy is one of the richest and most useful renewable energy sources in the world. It contributes 16-20% of total electricity generation in the world. A trade-off between irrigation and power generation is essential in order to achieve optimal social benefits. Proper allocation of water to irrigation and optimal utilization of water for power generation is one of the most important areas of concern. The study is mainly concentrated on using educators, auxiliary services and inline axial turbines. It helps to identify the energy recovering potential in terms of closed conduit. About 90% excess released through irrigation gates can be used for inline turbines. The inline turbine will also be exploited during the lower release where the main turbine could not be used during lower releases of water to irrigation. The remaining 10% water can be used for educator pumping and auxiliary services. The system of retrieving energy potential can be implemented in an agricultural to hydro power dependent irrigation projects. A pilot study on Dhom (2X1 MW) irrigation dependent hydroelectric plant, MAHAGENCO, Satara, Maharashtra has been conducted in order to tap the water during the lower release from the reservoirs. This paper emphasizes the methods of utilizing untapped energy during the lower & higher water release in irrigation dependent hydro power plant.

1. Introduction
In view of the global renewable energy production is steadily increasing to meet demands for clean and reliable energy. Presently, Hydropower contributes 16-20% of total electricity generation in the world and turbine is the power conversion component in hydropower plant. The International Hydropower Association (IHA) reports that renewable comprise 23% of the global electricity mix as of 2014, with 16% of the world’s energy production coming from hydropower [1]. A study by the World Energy Council (WEC) shows the hydro power generation accounts about 71% of all renewable energy [2]. Hence, hydro power plays a vital energy player in a world scenario with its outstanding characteristics of sustainable, clean and environmental source of energy. Water resources and their management aims for two major economic activities which are irrigation crop production and hydro energy generation. These two activities are often referred as water for crop irrigation as a static asset and hydro power generation as a dynamic asset [3]. Thus, dynamic management approach is critical for multipurpose reservoirs in order to achieve optimal social benefits. A study conducted at International Water Management Institute (IWMI) has shown that the demand for water is to increase by 50% by the year 2025 [4]. The importance of sustainable water – use efficiency is vital in a water resources sector [5].
Among the renewable energy sources, hydropower generation is one of the primary sources which date back to 1770s. Presently, The International Hydropower Association (IHA) reports that renewable comprise 23% of the global electricity mix as of 2014, with 16% of the world’s energy production coming from hydropower [1].

1.1 Literature Review
Hydraulic turbines are rotary machine which utilizes the potential and kinetic energy that converts into a useful mechanical energy [6]. Hydropower turbines are of two types namely impulse and reaction type. Impulse Turbines are high head, low discharge, and low specific speed and operate at atmospheric pressure, while the reaction turbines operate under low and medium head with high specific speed and operate under variable pressure. Especially Kaplan turbine is a reaction type mainly used to create the power from the low head and to provide loading at large flow rates. Kaplan turbines are always pre-dominantly engaged in an agricultural to hydro power water transfer projects [7]. Most of the low head reservoirs call for a dynamic allocation of irrigation crop production and hydro power generation. A tradeoff between irrigation and power generation is essential in order to achieve optimal the social benefits. In this scenario, all hydro power generating companies bound to respect pre-defined monthly release targets reflecting the agricultural demands [8].

A storage type hydroelectric irrigation power plant possesses a high capacity factor of around 50% as compared to 10% and 30% of solar and wind power [9]. A plant capacity is selected based on the annual rain fall pattern, storage capacity, gross head, flow rate available, capacity factor etc. On the operation point of view, a hydro turbine is subjected to cavitation, erosion, fatigue which dictates operational conditions in turn invariably affects the exploitation of the units [10]. Most of the irrigation dependent hydro plants are of low/medium head which employ the reaction turbines. Hence, reaction turbines are subjected to trailing edge cavitation, leading edge cavitation, draft tube swirl cavitation, inner blade cavitation and travelling bubble cavitation [11]. In hydraulic turbines, due to cavitation: the machine performance drop, high and low pressure is developing, noise and vibration level increases. Hence, standard guidelines are issued by the regulatory authorities for safe running of plants and that limits minimum discharge in which the plant to be operated. A study [12] has shown that in hydro power generation projects involving impounding of water, adequate water is required to be released round the year to meet the needs of the downstream users and flora and fauna to maintain the eco system in that area. However, during the minimum flow released to the canal systems could not be utilized for power generation. In view of the above, some of the energy potentials at irrigation dependent power plants could not be tapped because of the limitation imposed on the operation of the power units. In addition to the above, a study [13] suggested that the hydro plants are not immune from unexpected severe incidents during the operation periods especially floods related damages. Some of the references [14] show that the flood related damages in hydro plants are steadily increasing due to the economic activities in flood plains and global warming. The work [15] elaborates on the mathematical model generated for the optimization of power generation by minimizing the water consumption and also the dynamic programming approach is explained. A paper [16] focussed on the different ways of retrieving energy potential in an irrigation dependent power plant. In order to minimize the damages, disturbances in generation various guidelines are issued time to time by the regulatory authorities like National Disaster Management Authorities (NDMA), Central Electricity Authority (CEA) and Central Water Commission (CWC). In this area, limited research has been attempted on the irrigation dependent power units towards optimal use of energy. Recent flood related incidents in hydro power plants like Kopili hydroelectric plant, Assam and Bhatghar hydro power plant, Maharashtra have opened up for discussion for safe operation of power plants. During the flood related incidents in a typical hydro power plant, the existing pumping system becomes inactive due to the chances of short circuit and operational limitations. In this connection, the use of standby generator is also inactive. In such a catastrophic situation, the use of educator jet pump will be appreciable in order to avoid the flooding or the minimal damage to the plant equipments and systems. Hence, the present paper addresses the models and methods for utilizing the untapped energy potential at irrigation to hydro power water transfer schemes especially to utilise the
Environmental Flow (EF) and unscheduled minimum flow for irrigation through closed conduits by exploiting educator and inline hydro turbines.

2. Problem Statement and Methodology

Proper allocation of water to irrigation and optimal utilization of water for power generation is one of the most important areas of concern. Most of the irrigation based hydro turbines employ the reaction type turbines due to the advantages of low/medium head and high discharge through the irrigation canals. The capacity of the turbines based on the water release and head available in the reservoirs. However, during the lower release of water for irrigation and regulation of mandatory water release for flora and fauna, the water release in the irrigation gates are been utilized. The power units of reaction type could not able to tap the energy due to the restriction on the lower discharge conditions, the turbine may subject to cavitation and leads to noise and vibration and subsequent catastrophic failure of units. This is a case of universal in nature for irrigation storage dependent power generating units. This condition leads to reasonable generation loss to the power generating units. A pilot study on Dhom (2X1 MW) irrigation dependent hydroelectric plant, Mahagenco, Satara, Maharashtra has been conducted in order to tap the water during the lower release from the reservoirs. This paper emphasizes the methods of utilizing untapped energy during the lower & higher water release in irrigation dependent hydro power plant.

2.1 Salient details of Dhom Hydroelectric plant

DHOM 2 X 1 MW Capacity Hydro Power Station has been constructed at Vyahali dam near Wai, Satara district, Maharashtra. The dam lies right bank of river Krishna and the two separate outlets, one for Irrigation Discharge (ID), other for power have been embedded in the right bank of the dam. Dhom left bank canal bifurcates from right bank canal via embedded on downstream side is shown in Figure 1. The rain fall data and the energy utilized and the excess water release in irrigation gates are given in Table 1 & figures 2. The features of power plants are,

1. Installed capacity = 2 X 1MW
2. Annual design Energy generation = 10.56Million units (MUs)
3. Average Rain fall in catchment area 1500 – 6250 mm
4. Gross dam storage 382 MCM
5. Average inflow of water 423.91 Million Cubic Meters (MCM)
6. Live storage 331MCM
7. Design head 18 m
8. Minimum draw down level MDDL 733.08 m
9. Design discharge 14 m³/sec
10. Diameter of penstock 2.5 m

From the data collected, the average power generated by the two units from the year 2005 to 2018 (Table 1) is 7.247 million units per year. The capacity factor of generating unit is,

\[
\text{Capacity Factor} = \frac{\text{Average energy generated per year in kWh}}{\text{Installed capacity in W} \times 24 \times 365} = \frac{7247000}{(2000 \times 24 \times 365)} = 0.463
\]

So, it has been observed that the plant is working at its 40% of capacity. The maximum discharge through the power plant is 500 cusec and irrigation requirement is 900 cusec at a time. The total release of water for irrigation by left and right bank canal at a time is 650 cusec and 235 cusec respectively. Due to simultaneous discharge of water from both the canal, 400 cusec water releases continuously causes generation loss. It has also remarked that the project report design working table schedule is not followed. Due to which no yearly design generation of 10.597 million units is achieved since from commissioning. It has been also observed that average energy loss per year is 2.6919 MU. Thus total units lost per year are 2691900kWh. Therefore the power generated from this loss would be,

\[
\text{Power loss=2.6919*1000000} = 311.56 \text{ kW}
\]

So, the additional power of around 300 kW can be generated through the losses.

The data from year 1991 to 2018 in Table 1, Figure 2 shows that the water released through the irrigation gates at minimum discharge during the high rain fall period and maximum discharge during the low rain fall period.
Table 1. Irrigation and Machine Discharge

| Year | Average Rainfall (mm) | Irrigation Discharge Million Cubic Meter (MCM) | M/c Discharge Million Cubic Meter (MCM) |
|------|-----------------------|-----------------------------------------------|----------------------------------------|
| 91-92 | 967.60                | 98.54                                         | 0.77                                   |
| 92-93 | 910.20                | 54.35                                         | 19.40                                  |
| 93-94 | 1129.30               | 58.24                                         | 106.11                                 |
| 94-95 | 1170.90               | 37.42                                         | 90.23                                  |
| 95-96 | 660.60                | 92.36                                         | 21.60                                  |
| 96-97 | 1114.40               | 61.44                                         | 85.85                                  |
| 97-98 | 1086.60               | 165.29                                        | 212.33                                 |
| 98-99 | 858.70                | 88.54                                         | 158.20                                 |
| 99-2000 | 852.90             | 27.65                                         | 236.56                                 |
| 2000-01 | 565.50             | 59.56                                         | 148.77                                 |
| 2001-02 | 702.30             | 86.46                                         | 155.55                                 |
| 2002-03 | 532.50             | 163.44                                        | 214.51                                 |
| 2003-04 | 661.20             | 56.35                                         | 128.30                                 |
| 2004-05 | 1164.20            | 48.48                                         | 191.58                                 |
| 2005-06 | 1454.80            | 30.32                                         | 303.90                                 |
| 2006-07 | 1504.00            | 57.35                                         | 342.24                                 |
| 2007-08 | 1200.00            | 27.85                                         | 284.60                                 |
| 2008-09 | 1009.00            | 154.24                                        | 211.01                                 |
| 2009-10 | 1163.00            | 29.84                                         | 160.53                                 |
| 2010-11 | 984.00             | 52.21                                         | 155.42                                 |
| 2011-12 | 953.00             | 90.87                                         | 194.20                                 |
| 2012-13 | 811.00             | 58.51                                         | 158.56                                 |
| 2013-14 | 1082.00            | 161.32                                        | 198.73                                 |
| 2014-15 | 1106.00            | 58.76                                         | 174.71                                 |
| 2015-16 | 580.00             | 58.90                                         | 75.24                                  |
| 2016-17 | 888.00             | 165.39                                        | 185.68                                 |
| 2017-18 | 897.00             | 46.24                                         | 20.19                                  |

Figure 1 Layout of Dhom Irrigation canal

Also, the behavior of machine during high and low rainfall period is seen. Hence, a proportionate energy loss at the given head and discharge due to which the power units could not able to operate having constraint of low discharge and also the period when high releases, the units are operating at maximum load. Also there is a change in rainfall pattern, frequency and quantity as one of the effect of the global warming which may cause the flooding over any. Similarly sudden power failure may also disrupt the routine functioning of plant due to improper working of auxiliary circulating pumps. This
cascade of low and high discharge has been accommodated by adopting following components of energy recovery model as shown in Figure. 3.

![Figure 2. Rainfall Vs Irrigation and Machine Releases](image)

**Figure 2. Rainfall Vs Irrigation and Machine Releases**

1. Dewatering component – an Eductor
2. Closed conduit inline propeller turbine in the existing suction line of the circulating pumps for cooling and auxiliary services
3. Arrangement of split type Kaplan/propeller turbines installed in the structure of the irrigation gates
4. Arrangement of very low head Kaplan turbines in the canal in which the energy developed through the water release from the turbines and the release through irrigation gates.

A typical reaction turbine plant is provided with number of pressure tapings such as pressure equalizing line connecting the upstream and downstream of the main inlet valve, drain lines on penstock at inlet and outlet of the main inlet valve and cooling line tapping for circulating pumps for generator cooling, bearing cooling, lubricating oil cooling and other auxiliary services. The figure 4 shows the existing layout of the water conduit at main inlet section of a hydro turbine. Sudden power failure, overflowing of existing area of power plant may create circumstances of improper and discontinuous working of hydro power plant. This paper emphasizes on how the excess water in the hydro power plant can be restored by employing suitable methods or devices. Additional dewatering system has been suggested supporting the existing auxiliary circulating pumps. Figure.5 shows the existing layout of hydro power plant.

**3. Proposed methodology for eductor pumps**

The penstock of the existing hydro power units is of 2500 mm diameter each in which flow to the turbine passes. Further, the auxiliary circulating pumps of capacity 15 kw each is provided to govern oil cooling, generator air cooler and other auxiliary services. The suction of auxiliary circulating pumps draw water
from the tapping provided in the penstock of the turbines. Usual circulating pumps require electricity for their operations.

![Figure 5: Existing layout of Hydropower Plant](image)

Figure 5: Existing layout of Hydropower Plant

In case of unavailability of power and the brimming in the power plant, make these pumps redundant. Thus, the discharge and velocity of flowing fluid has been effectively used in solving such real time problem without using the external driving force as electricity. The Venturi based pumps which are worked on fundamental principle of flow dynamics known as Bernoulli’s principle and follows the basic Continuity equation known as an Eductor has been suggested. Eductor (Figure, 6) is functioning without any electricity and rotation of any parts such as impeller, motor. Any type of educator is having three basic portions; Motive portion, Suction portion and Outlet portion. Motive portion takes in motive (primary) fluid under high pressure and allows it to flow through the nozzle created thereafter. Suction portion insist the suction of suction (secondary) fluid. The suction fluid gets in and transported by motive fluid with the increased velocity of motive fluid after passing through nozzle. There is a kinetic energy transfer takes place in the Outlet portion due to the friction between these two fluids and increased velocity. This will make two fluids to leave outlet portion having diverging end with increased pressure and reduced velocity. The various parts diagram of eductor is shown in and Figure, 7 show the modified layout of energy recovery model in a hydropower plant.

![Figure 6: Concept of Venturi based Eductor](image)
The existing layout of services to turbine units along with penstock can be modified to address the problem of reducing the loss of water or converting this loss into a potential use by modifying the layout. Alternative for dewatering the excess water can be used in the new arrangement to improve the conditions which may arise due to sudden power failure. Eductors can be used as fixed or portable installation. This ability of educator of working without power and rotating parts reduce the cost of operation and maintenance, portable eductors increase its flexibility as per requirement of time and place. This will certainly minimizes the chances of risk during the flooding of plant. Eductors are available according to the purpose of work like mixing eductors used in chemical industries, sand and mud eductors useful at the site of reservoirs to pump accumulated material. Also solids handling eductors are dealing with dry and wet solids, multinozzle eductors in operation for suction fluid containing solids and semi solids. Deep well, recirculating and priming eductors are useful in lifting water with few variations. The discharge from the eductor will be calculated to know the performance of this Bernoulli’s based pumps over the submersible or borehole pump. The discharge is calculated on the basis of following assumptions:

1. The water vapour pressure is assumed = 3.023m of water column
2. Required Net Positive Suction Head (NPSH) = 10.13m of water column
3. Performance ratio = 1.1 (if both motive and suction fluid is water)
4. The atmospheric or barometric pressure required for NPSH is calculated on the basis of altitude of a dam.

The sample calculation to determine the size of eductor in case of a Dhom dam is shown as follows.
1. Design head of dam (H_d) = 18m
2. Assume suction head (H_s) = -3m
3. Discharge head (H_d) = 10m
4. Total Discharge Head (TH_d) = 13m
5. Operating head (H_o) = H_d-H_s = 21m
6. Available NPSH (NPSH_a) = 3.47m
7. Suction flow (Q_s) = 5kW of monoblock pump running for 6 hours for Discharges of 12 cumec
8. Motive flow (Q_m) = Q_s/1.1 = 10.9 cumec
9. Total discharge (Q) = Q_s+Q_m = 22.90 cumec
10. The size of eductor required is 0.0635 m with velocity of 2.438 m/sec

4. Result
Eductors can replace the conventional pumps on many factorssuch as saving on electricity, continuous discharge without electricity, portability. The calculation of discharge required through eductor for other dams based on net head of respective dams and energy recovery is given in Table 2. This data can be used to know the size of eductor. By using eductor the saving in electricity can be possible since NO electricity required for this pump to run. The necessary calculation from Table 2 shows that if conventional pump of 5kW would run for 6 hrs at the cost of Rs.5/- per hour, it would require Rs. 54000/- per year in case of normal operation. In addition to the normal operation, during the catastrophic situation, the use of educator jet pump will be appreciable in order to avoid the flooding or the minimal damage to the plant equipment and systems. Further, the average energy loss due to low discharge is,
The irrigation canals. The installation of inline dependent hydroelectric plant, Mahagenco, p irrigation on farming System2010, 13, pp.

No. Sr. Name of Dam Design Head in m Suction head in m Discharge Head in m Total Discharge in mm Operating Head in m NPSH in m Discharge through Monoblock pump in cumecs Motive Flow in cumecs Total Discharge in cumecs Power of Pump in kW Running hours of pump Units consumed by pump per month Cost of running the pump in Rs/year
1 Dhom 18 3 10 13 21 3.47 12 10.90 22.90 5 6 900 54000
2 Kashee 21.2 4 11 15 25.2 2.50 18 16.36 34.36 6 8 1440 86400
3 Bharghat 26 5 12 17 31 1.56 24 21.81 45.81 7 7 1470 88200
4 Dudhganga 42 4 13 17 46 1.51 30 27.27 57.27 7.5 6 1350 81000
5 Panchet 45 3 14 17 48 3.49 33 30 63 8 8 1920 115200
6 Varasgaon 47 5 15 20 52 1.66 42 38.18 80.18 9 7 1890 113400
7 Bhira 48 5 15 20 53 1.54 45 40.90 85.90 10 6 1800 108000

Table 2. Potential for utilizing water for auxiliary services

The power lost through the irrigation release of an irrigation dependent power plant is about 311.56 kW derived from the equation 2. An additional power generation can be tapped by providing closed conduit inline axial turbine in the existing penstock section by modifying pressure line to accommodate a conventional inline axial flow turbine. An inline axial flow propeller turbine installed in the modified piping of 500 mm nominal bore can able to generate 150 kW of power with design head of 18 m with water velocity of 6.5 m/s at flow 1.3 m²/sec considering the efficiency between 80 – 85%. The power produced through the inline turbine can be used for internal load of power house and it can be optimally used to retrieve the lower releases and high releases at the irrigation canals. The installation of inline hydro turbine in the leading pipe from existing penstock will generate an additional energy of 300 units per hour will yield 2.592 million units per year.

5. Conclusion
A pilot study on Dhom (2X1 MW) irrigation dependent hydroelectric plant, Mahagenco, Satara, Maharashtra has been conducted in order to tap the water during the lower & higher release from the reservoirs. The study is mainly concentrated on using educators, auxiliary services and inline axial turbines. It helps to identify the energy recovering potential in terms of closed conduit power utilization by adopting inline axial flow turbine as well as by utilizing auxiliary services. About 90% excess released through irrigation gates can be used for inline turbines. The inline turbine will also be exploited during the lower release where the main turbine could not be used during lower releases of agricultural to irrigation. The remaining 10% water can be used for educator pumping and auxiliary services. The system of retrieving energy potential can be implemented in an agricultural to hydro power dependent irrigation projects.

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References
[1] Greg Schellenberg et al. 2017, Sedimentation and Hydropower: Impacts and Solutions, Hatch.
[2] World energy Council, https://www.worlgenergy.org/data/resources/hydropower
[3] A. Tilmant, Q. Goor, and D. Pinto2009, Agricultural to hydro power water transfers: Sharing water and benefits in a hydro power- Irrigation Systems, Hydrology and Earth System Sciences, 13, pp. 1091 – 1101.
[4] Seckler, David, Amarasinghe, Upali, Molden, David, Radhika and Barker. Randolph1990 to 2025, Worldwide Demand and Supply, Scenrio and Issues, Research Report 19. International Water Management Institute, Colombo, Sri Lanka.
[5] D. Suresh Kumar and K.Palanisami. Impact of drip irrigation on farming System2010, Evidence from Southern India, Agricultural Economics and Research Review; 23, , pp.205-272.
[6] Ece Ayli2019, Cavitation in Hydraulic Turbines, International Journal of heat and Technology, 23, pp. 334-344
[7] Munendra Kumar and A Nikhade 2015, Cavitation in Kaplan Turbines, Journal of Material Science and mechanical Engineering, 2(5), 425-429.
[8] A Tilmint, Van der Zaag, and P. Fortemps 2007, Modelling and Analysis of Collective management of water resources, Hydrology and Earth System Sciences, 11, pp. 711 – 720.
[9] Bhilal A. Nasir 2014, Design Considerations of Micro Hydro Electric Power plants, Energy Procedia, 50, pp. 19-29.
[10] Doina. Frunzaverde, V. Campion, D. Nedelcu, G. A. Gillichand G. Marginean, Failure Analysis of Kaplan Turbine Blade by Metallographic and Numerical Analysis, Continuum Mechanics, ISSN No. 1790 – 5095, pp. 60-66.
[11] M. K. Padhy and R P Saini2008, A review of silt erosion in Hydro turbines, Renewable and Sustainable energy reviews, 12(7), 1974-1987.
[12] Sharad K. Jain and Pradeep Kumar2014, Environmental Flows in India: Towards Sustainable Water Management, Hydrological Sciences Journal, 59(3-4), pp. 751-769.
[13] US Patent No. 8884454B2, Method and apparatus for improved hydropower generation at existing impoundments, 2009
[14] US7972108B2, Turbine and hydroelectric power plant for very low head.
[15] Jiqing Li, May Myat Moe Saw, Siyu Chen and Hongjie Yu 2020, Short-Term Optimal Operation of Baluchuaung II Hydropower Plant in Myanmar, Water.
[16] Maya Kurulekar et.al. 2020, A Pilot Study on Retrieving Energy Potentials during Minimum Discharge Through Irrigation Dependent Hydro Power Plants; Accepted for Publication. International Conference on Fluid Machinery and Fluid Power (FMFP 2020); IIT Guwahati