Integration of Technologies – Power Flow Controllers & Dynamic Line Ratings for RE Penetration

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Objective:

- Increase flexibility and capacity of existing power grid.
- Increase network flexibility for grid users at optimised OPEX, which allows for a larger share of RES and increased security of supply.
- Manage congestion within the grid without affecting system reliability.
- Defer CAPEX to build new lines by harnessing the hidden capacities of the existing system.

I. Introduction:

The integration of intrinsically variable R.E generations shall bring unpredictability in the form of sizeable fluctuations in power flows in transmission networks. It shall also further increase the need for grid reinforcement to guarantee security of supply. The power flows vary with time, seasonal variations as well as daily variations. The network additions to cater these power flows cannot be an economical solution always. Advanced transmission technologies must be tested, and the management of existing infrastructure must be improved. The new technologies like **Dynamic line ratings (DLR)** and **modular power flow control devices (PFCs)** are being tested, implemented and are being successful in their operations in many parts of the world. This paper focus on the idea of integration of both Dynamic line rating and Power Flow controllers to enhance the flexibility of existing transmission infrastructure, along with details of DLR & PFCs and variables effecting the loading limits of conductors.

Concept – Integration of Technologies

- The loadings of the transmission system depend on several variables like wind velocity, ambient temperature, solar radiation etc. and hence the capacity of the transmission line cannot be a static rather can be a dynamic rating. Reliable monitoring by network operators is a precondition to exploit this extra capacity.
- Some **Dynamic line rating devices (DLR)** are quick and easy to install and can precisely monitor a network's transmission capacity in real time. The resulting measurements are more accurate and open the possibility of exploiting additional capacity without compromising on safety margins. It should be noted that DLR technologies is not a substitute of grid development, but a complementary method to better exploit exiting infrastructures.
- **Power flow controlling devices (PFCs):** While devices like phase shifting transformers (PSTs) can be used to control power flows, alleviate congestion and free up available capacity, some advanced modular power flow devices are being successfully operated and are providing several advantages over traditional solutions, such as rapid deployment, scalability and redeployment. These modular power flow control solutions are being installed within meshed transmission and sub transmission networks and enables the operator to adjust transmission line reactance in real time to change power flows in the network.

- **Integration of both Technologies (DLR + PFCs):** With the integration of both the technologies, where PFCs could serve to route power flows through additional capacities provided by DLRs, the flexibility of the transmission system can be enhanced, and hidden capacities of the transmission system can be exploited.

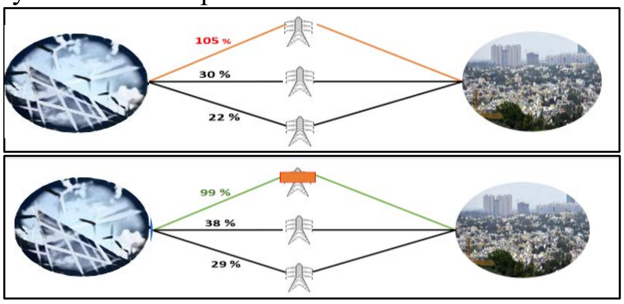

Fig3: Technology solving line overload

II. Conductor Loading:

Thermal current limit of conductor is defined as maximum amount of electrical current a conductor can carry before sustaining immediate or progressive deterioration.

Thermal rating of bare overhead conductor is a function of,

- Conductor material properties
- Conductor diameter
- Conductor surface conditions
- Ambient weather conditions

The first two of these properties are specific to chemical and physical properties. The third may vary with time, and that variation is dependent upon ambient atmospheric conditions other than weather. The fourth, weather, varies greatly with the season. If we consider that the conductor is mechanically properly designed, and sag is not a limiting factor for temperatures below the maximum allowable temperature of the conductor, then the weather conditions have the dominant effect on line's ampacity. The weather conditions directly influence on cooling power, mainly through convective cooling provided by wind.

The typical equation that describes the change of temperature in non-steady state condition is as follows,

$$\frac{dT_c}{dt} = \frac{1}{mC_p}[R(T_c)I^2 + q_s - q_c - q_r$$

Where,

q_s = Solar heat gain
q_c = Convection heat loss
q_r = Radiated heat loss

The above equation describes that when the heating is greater than cooling, the temperature will rise proportionally to the mass and specific heat of the conductor and vice versa. Since the atmospheric conditions around the conductor constantly vary as well as the conductor load, the temperature of the conductor also varies accordingly. The conductor temperature may vary not only with the line current but also the weather conditions may have significant impact.

III. Dynamic Line Rating (DLR)

DLR technologies can monitor the line parameters along with the external parameters like weather conditions to determine the real-time capacity of the line. The parameters can be monitored though direct and indirect methods.

Direct measurements are based on the measurement of the conductor temperature or least one physical parameter of the line which is directly related to it such as sag, mechanical tension, vibration frequency or ground clearance.

Conductor Temperature measurement: This is one the direct method of monitoring conductor parameters. This method requires installation of devices on the conductor, which can be powered by the magnetic field generated by the line current. The conductor temperature can be measured through,

- Temperature Sensors: Temperature sensors measures the conductor temperature and transmit the measurements to a central station via radio communication. These sensors are point sensors that can be installed at specific locations over the span of line sections.
- Optical fibre: the temperature measurement through optical cables, is carried out by the analysis of the phenomenon of scattering produced by a correct laser beam sent into the optical fibre.

Line Tension Methods: This direct measurement method involves the measurement of mechanical tension line. This method uses the load cells, which measure the mechanical tension and transmit the information to the control centre. The transmitted data is used for the calculation of temperature and therefore of the real-time ampacity.

Line Sag Methods: This direct method measures the sag in the fixed spans of the line by using optical sensors, ultrasonic or radar.

Vibration Frequency: This is one of the direct measurement method. The analysis of the conductor vibration can be used to detect the fundamental frequency of the span, which is a function solely of sag.

Indirect methods use weather parameters, measured by weather monitoring devices, and the load current to calculate the temperature of the conductor, through theoretical methods. These indirect measurements are also simplest to implement as they do not need to be installed on the line itself and can be installed on the towers. The measurement devices measure the speed & direction of wind, ambient temperature and the solar radiation. The wind speed is the one important factor in determining the temperature of the conductor, hence these devices should provide measurements with good accuracy.

The direct methods provide a true information of the physical quantity of the line being monitored, but it is necessary to install the sensors at multiple locations along the line. Indirect measurement methods use weather stations that are not directly installed on the conductor and measures for a span of area which can cover major portion of major span of conductor. Optimal utilization of both the methods can fetch better results to estimate real time capacity of the transmission lines.

IV. Power Flow Controllers (PFCs)

The power flow controllers being discussed in the paper are basically series FACT devices which are modular and are easy to deploy, monitor and redeploy. These devices are clipped onto line conductors, typically at each end of multiple spans and can be installed or relocated in a very short time. These devices.

Traditional devices like example Fixed series capacitors and phase shifting transformers can enhance power flow and stability in the system but imposes challenges in terms of scalability, sizing, deployment, operational issues. requires enough space in substations for installation and these devices are designed for specific locations.

The modular series FACT devices are installed on each phase of the conductors. These devices inject reactance and push power away from the transmission circuit, thus controlling the power

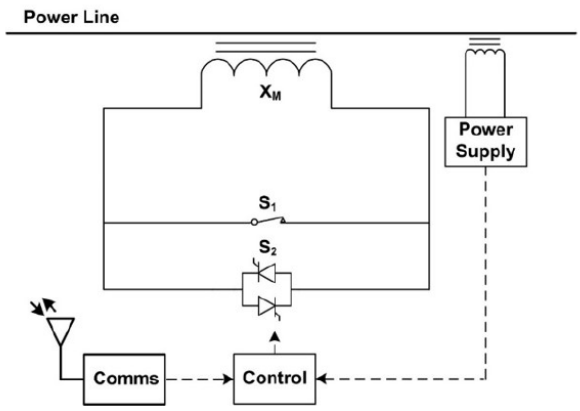

Figure 4: Equivalent circuit of PFC, Source: Ref [2]

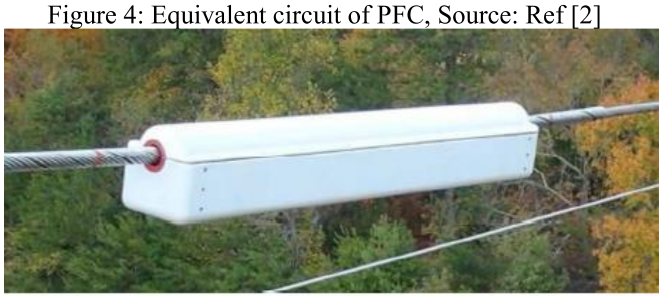

Figure 5: Series FACT device clipped on Transmission Line Source: Ref [2]

The device consists of a split transformer hung from the conductor. Main power conductor forms the primary winding of the transformer. When the secondary winding is shorted, the unit operates in monitoring mode and negligible inductance is coupled in series with the line. When the secondary winding is opened, the magnetizing inductance of the transformer is coupled in series with the line and the unit operates in injection mode. While and individual device have a very small effect on impedance of a line phase adding numbers of them can change reactive impedance by several percent.

These devices can be operated in injection mode or in monitoring mode by controlling either through preprogramed current threshold or manual remote control of the devices from operating centres.

V. Integration of Technologies (DLR + PFCs)

The Integration of technologies is explored to enhance the flexibility of the system operation. A multi measure approach would enable networks to accommodate larger volumes of power and transport it to the demand centres, making better use of existing assets.

The trend towards using seasonally adjusted ratings and ambient adjusted ratings reflect that traditional static line ratings are often or usually over conservative. The ratings provided by Dynamic line rating technology combined with forecasting tools, can be logical extension of the above trend, by providing actual capacity ratings based on actual conductor behaviour and forecasted weather conditions.

In case of renewable generation (RE), the congestion is created due to seasonal variations and the lines are underutilized during the rest of period. As power flow devices are modular and can be controlled remotely, these devices can help in controlling the power flows i.e., routing the power flows in other paths with spare capacities, where these spare capacity data can be provided by the DLR technologies along with forecasting tools in real time. During high RE generation these technologies can be cumulative, enabling greater flows to pass through what had previously been considered as a congested line. Due to their compact nature the same set of devices can be installed and reinstalled at critical locations whenever required.

These technologies either by integration or individually can be implemented to harness hidden capacities, however overloaded lines in critical corridors should be dealt with uprating methods i.e., either by increasing the thermal capacity of line or voltage upgradation.

VI. Future Work - Intention

- Identification of case where there are overloading for a short time due to integration of RE generation.
- Gathering of network data required for the power system studies. Network data like transmission system connectivity, generation and load data, transmission system equipment parameters.
- Network model and simulation studies, Transmission line forecasting techniques and algorithms.
- Stakeholder engagement and real-time pilot project by combination of installing the DLRs, PFCs and forecasting techniques.

VII. Typical case with Assumptions, where Multiple Technologies can be implemented:

The evacuation network near the Nagjheri hydro power, which is in northern part of Karnataka is being severely overloaded as per the operational feedback report published by National Load Despatch Centre. The hydro generation present in the vicinity are Nagjheri (Installed capacity:900MW), Kodasally (Installed capacity120MW), Kadra (Installed capacity150MW) and there is a nuclear generation at Kaiga with installed capacity of 800MW. The total installed capacity in the vicinity is around 2050MW.

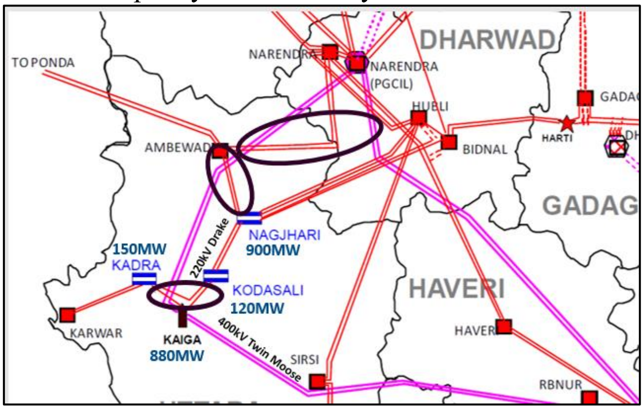

Figure 6: Network Map near Nagjheri

The lines that are being severely overloaded as per the report (ref [4]) are 220kV Nagjheri – Ambewadi D/C, 220kV Ambewadi – Narendra D/C, 220kV Kaiga – Kodasally S/C and 220kV Kadra – Kodasally S/C. From the SLD it is can be seen that there is high capacity 400kV corridor connected between Kaiga – Narendra and Kaiga – Gutty. The lines can be overloaded assuming that the power is taking the route through 220kV although a 400kV connection is available.

The thermal capacity of 400kV Twin Moose varies from 874MW at ambient temperature of 45^0C to 1108MW at ambient temperature of 30^0C [ref 5]. There are two interconnected high capacity 400kV corridors available in the system.

For this case with the integration of technologies like DLR and Power flow controllers, the power may be routed from the overloaded 220kV lines to high capacity 400kV corridor along with reconductoring few corridors with high performance conductors. The DLR technology along with forecasting tools can provide the dynamic thermal capacity available and the PFCs can route the power to 400kV corridor. The application of technology, design of the PFCs and optimal location of DLRs along with reconductoring can be identified through system studies along with the stakeholder engagement.

VIII. Conclusion

The Government of India has presently set an installed capacity target of 1,75,000 MW from renewable energy (RE) sources by 2022. This includes 1,00,000 MW from solar, 60,000 MW from wind, 10,000 MW from biomass and 5000 MW from small hydro power. Within the target of 100,000 MW for solar energy, 40,000 MW would be from solar roof tops and the balance 60,000 MW would be from utility level grid connected solar.

Category	Capacity addition				
	2017-18	2018-19	2019-20	2020-21	2021-22*
Solar					
Rooftop	5,000	6,000	7,000	8,000	8100
Ground Mounted Solar	10,000	10,000	10,000	9,500	7637
Total Solar	**15,000**	**16,000**	**17,000**	**17,500**	**15,737**
Wind	4,700	5,300	6,000	6,700	6,334
Biomass	750	850	950	1,000	1,005
SHP	100	100	100	100	100
TOTAL	**20,550**	**22,250**	**24,050**	**25,300**	**23,176**

*the capacity has been adjusted to arrive at total capacity from RES of 1,75000MW by 2021-22

Figure 7: Year Wise targets of Renewable Energy Sources. Source: Draft National Electricity plan, Central Electricity Authority

To integrate these huge targets of RE generations, there is an emerging need for rethinking, in designing the system to enhance the existing capacity through uprate/upgrade, with the support of new technologies & their integration, along with strengthening of the grid.

References

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[3] Dynamic line rating for overhead lines – V6 – entsoe

[4] Operational feedback Transmission Constraints – October 2017, Report by National Load Despatch Centre.

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Biographies

Jeentendra Bisht is Head of Strategy & Policy Advocacy at Sterlite's Solutions Business. Acting as a cross-functional 'radar' to aid Sterlite Power's response in the changing operating environment, Jeetendra has been leading a group of analysts that deliver Power Systems Studies, Policy Advocacy Agenda, Market Research & Business Analytics.

Jeetendra has been serving energy sector for 10+ years in various roles working with the largest private transmission company, a leading Wind developer & Turbine OEM and leading Energy sector BI providers. Jeetendra is IIM Calcutta alumnus (executive programme) 2012 batch.

Mohan Babu Paladugu is a Power Systems professional having extensively worked on Transmission Planning, Load Flow Analysis, Short Circuit Analysis, Transient Stability, Power system protection and Harmonic Analysis. Mohan has expert skills on simulation software such as MiPower, ETAP, PSSE etc. Over past 6 years, Mohan has gained experience of working with Power Consulting, Power Generation & Power Transmission companies. He is currently associated with Sterlite Power Transmission Limited and responsible for facilitation and integration of next generation technologies in power grids.