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An approach to Energy management system

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ABSTRACT:
Electrical power transmission system forms an important part of the electricity network required to transfer bulkamount ofpowerproducedatremotelylocatedgeneratingstationstotheloadcentres.Inmostofthecountries,includingIndia,the electricity sector has a vast interconnected system of generation, transmission and distribution network, which requires modern computer-aided operation and control system. Such a system is called 'Energy Management System (EMS)', conventionally based on Supervisory Control and Data Acquisition (SCADA) features. With the recent development of dielectricaswellasconductingmaterials,powerelectronicdevices,informationtechnologyandautomationsystem,anew class of transmission and control equipment is being used and the energy management system is also beingmodernized. Recent blackouts in India and other countries have prompted the use of Wide Area Monitoring Control and Protection System (WAMCPS) based on synchrophasor technology for real time monitoring of dynamic states and security of the system. This paper describes the present status and future developments in the electrical power transmission, energy managementsystem,andemergingtechnologies,specificallyintheIndiancontext.
Keywords: Power Transmission; Energy Management System; Indian Scenario; New Technology

Role of Power Transmission in the Electricity Sector

Electric power has become the most essential commodity and vital input for the growth of any economy. It facilitates development across various sectors such as manufacturing, agriculture, commercial, education, railways, etc., to achieve economic growth. Accelerated economic growth of thecountry,alongwithglobalizationandliberalization, willresultinhighincreaseinpowerdemandinfuture. To sustain the pace of growth, overall expansion of theelectricitysectorincludinggeneration,transmission anddistribution,withadequatereliability,isrequired.

Indianpowersectorisoneofthemostdiversified sectors,consistingofavarietyofgenerationresources includingconventional/non-conventionalsources,to meet the demand. Utilizing the availability of these diverseresources,thecountryhasbeencontinuously planningthegenerationcapacityaddition.AsofMarch 2015, the total installed generation capacity in the country is about 267.6 GW (CEA Report,March2015), consisting of 164.6 GW of coal-based, 23.0 GW of gas-based, 1.2 GW of diesel-based, 5.8 GW of nuclear, 41.3 GW of large hydro and 31.7 GWof renewable energysources.

The generation mix of conventional sources is 87%, while the renewables contribute about 13% of the non-conventional sources. Coal still dominates (61%) as fuel resource in the overall electricity generationportfolio.Thecountry'spresentpeakpower demand is about 148.2GW, whereas energy requirementisabout1067billionunits(BU).However, there is still a shortage of about 4.7% and 3.6% of thepeakdemandandenergyrequirement,respectively.

Electricity demand in the Indian powersystem is expected to increase to more than 300 GW bythe

endofthe12thfiveyearplan(2016-17).Towardsthis demand, the Government of India has an ambitious plantoaddabout88GWduringthe12thplanthrough conventional resources. In addition, 30-40 GW capacity is also envisaged to be added through renewable/non-conventional sources during the 12thplanperiod.
The natural resources of electricity generation inIndiaareunevenlydispersedandconcentratedina few pockets, while load centres are dispersed in all the regions. In this scenario, to cater to the bulk demand at the load centres, either natural fuel such as coal/gas needs to be transported over a long distancetorunthepowerplantsneartheloadcenters or the electrical power has to be transmitted over a longdistancethroughtransmissionlines.Ithasbeen found that the transmission of power from pithead coal-based power plants and remote located hydro plantstotheloadcentresiseconomicalandtechnically viable from the energy management perspective through High Voltage AC (HVAC) or High Voltage DC (HVDC) transmissionnetworks.
Due to large demography, demand varies over the day/week/month as well as on seasonal/regional basis.Tocatertosuchavariabledemandpattern,the generationportfolioshouldhaveamixofvariousfuel technologies.Therefore,thetransmissionsystemneeds tobestrengthenedtotransferpowerfromgenerating plantshavingamixoffuelsacrossregionsandstates as well as to cater to the demand under alloperating conditions. In an open electricity market, wherein long-term,medium-termandshort-termcontractsare takingplace,thepriceofelectricitydependsuponthe supply-demand balance. The consumer aspires for affordable and reliable power while the supplier's concernisonmaximizingtheprofit.Thetransmission network plays a key role in managing/wheeling electricityfromoneparttootherpartofthenetwork tomeetthetransactions,whileensuringreliabilityand security ofsupply.
Thus, the transmission plays a vital role in the overall development of the power system. It is the central link in the entire electricity supply delivery chaininterconnectingsourcestothedistantlylocated loadcentres. A robust and reliable transmission networkhastobeplannedtoensuresupplyinasecure manneratreasonablecost(Gonen,2009).Italsooffers thesellersandbuyersofelectricpowerachoiceand, thereby,facilitatesdevelopmentofanopenelectricity market.

Energy Management System
In the present day large interconnected power systems, the demand forpower is always increasing, which requires expansion of the transmission networks.However,additionofnewtransmissionlines isnot always feasible due toeconomical, environmentalandrightofwayconstraints.Thisleads to the stressed operation of the system and calls for its continuous monitoring as well as assessment of security and stability. Increased vulnerability of the modern power systems toblackouts under contingencies, demands for the development of monitoring and assessment tools. Further, the operatingconditionsandthedynamicsofthesystem change frequently with the changes in loading conditions. To understand and predict the operating conditionsandtomonitorthevitalparametersofthe system closely, automation, control and application software are required for quick response to the operating conditions as well as to perform the forecasting and postmortemanalysis.
Sincethelast4-5decades,fortheoperationand control of the power system, a combination of computer and communication hardware along with software application suites, is being utilized by the powersystemutilities,whichiscommonlycalledas the 'Energy Management System' (EMS)(Talukdar andWu,1981).Thissystemhasbeenusedinmostof the power systems across the globe mainly at generation and transmission levels, which acquires measured quantities, such as Root Mean Square (RMS) values of the bus voltages, branch currents andpowerflowsatascanrateof2-10s.Toscanthe measuredquantities,RemoteTerminalUnits(RTUs) areinstallednearthesubstationsorgeneratingstations toreceivetheanaloguemeasurementanddigitalstatus signals from the field equipment, which are to be monitored remotely. The RTUs are equippedwith

analogue/digital measurement devices, a suitable Analogue toDigital (A/D) converter, and communicationchanneltosendandreceivethedata to control centres and also the control commands to thefieldequipment.Conventionally,telemetrylinks have been used for data communication, which are beingreplacedbyfibreopticlinks.
Inthepast,theimportantapplicationoftheEMS hasbeentheSupervisoryControlandDataAcquisition (SCADA). The SCADA system spools the required power system measured quantities from the RTUs, filters and analyses it for various applications. The filtered data is further used by other software applications such as state estimator, security enhancement, contingency analysis,and shortcircuit analysis.AtypicalarchitectureoftheEMSisshown in Fig.1.
ImportantcomponentsoftheEMSapplications' suiteincludesSCADAapplication,communicationand control applications, network management, state estimation, contingency analysis, economic load dispatchoroptimalpowerflow,AutomaticGeneration Control(AGC),securityassessment,faultdetection, isolationandrestoration,dispatchertrainingsimulator, andvariousofflinetoolssuchasloadflow,playback, historian,etc.
Thedispatchertrainingsimulatoristhetoolused to provide training on EMS applications to the operatorsresponsiblefortheoperationandcontrolof the power system networks. In large electricity networks such as those in India, hierarchicalarchitecture of EMS has evolved, havingcontrol
centresatnationallevel,fiveatregionallevelandone ineachofthestatesknownasNationalLoadDispatch Centre (NLDC), Regional Load Dispatch Centre (RLDC) and State Load Dispatch Centre (SLDC). The required application software for functioningof electricity markets is also being embedded at the controlcentres,tobeoperatedbythesystemoperators (SOs). The EMS is continuously being modernized (Wu et al., 2005) utilizing the new technologies of computingandcommunication.Oflate,thedistribution systems are also being provided with SCADA systems, commonly known asDistribution Management System (DMS) or Distribution Automation System (DAS), where application functions are different, such as load estimation and forecasting, Volt/Varmanagement, network reconfiguration, automatic billing, equipmenthealth monitoring,etc.

Present Status of Transmission Network
Existing Transmission Network in India
Electricity is a concurrent subject in India. Both the centralandthestategovernmentsareresponsiblefor the development of this sector. There are number of centralgenerationutilitiessuchasNationalThermal Power Corporation (NTPC), National Hydro Power Corporation(NHPC),TehriHydroDamCorporation (THDC), North Eastern Electric Power Corporation Ltd. (NEEPCO), SatlujJalVidyutNigam Limited (SJVNL),NeyveliLigniteCorporationLimited(NLC), etc. Power Grid Corporation of India Limited (POWERGRID) is the Central TransmissionUtility

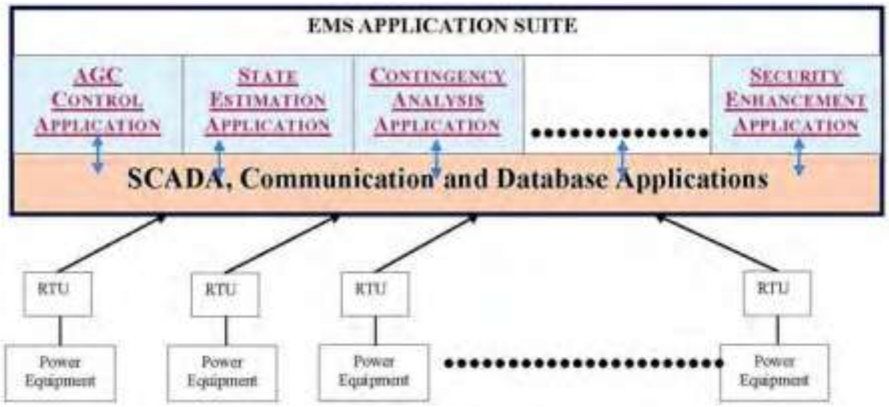

Fig. 1: Typical Energy Management System Architecture

(CTU).At the state level, separate Generation company (Genco) and Transmission company (Transco) have been formed. Distribution of power is under the purview of the respective state utilities. Central Electricity Regulatory Commission(CERC) is the regulatory authority at the central level with State Electricity Regulatory Commissions (SERCs) at the state level. For the sake of better coordination between the state utilities, the country has been demarcated into five electrical regions, namely NorthernRegion(NR),SouthernRegion(SR),Eastern Region (ER), Western Region (WR) and North Eastern Region (NER), as shown in Fig. 2.
Overdecades,arobustinter-state/intra-stateand inter-regionaltransmissionsystemhasbeenevolved inthecountry,whichfacilitateswidespreadreachof power over the vast areas. At the time of independence,maximumvoltageleveloftransmission was at 132 kV, which was subsequently increasedto 220 kV in 1960 and 400kV AC in 1977. To reduce theRightofWay(ROW)requirementfortransmission lines along with large quantum of power transfer requirement and to overcome constraints on availability of land for substations, 765 kV AC transmission voltage and Gas InsulatedSubstations

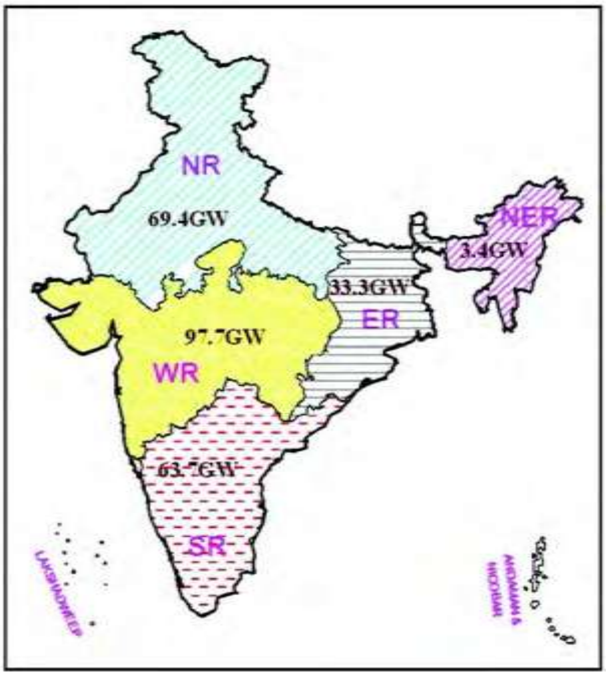

Fig. 2: Five Electrical Regions of India (CEA Report, March 2015)

(GIS) are now being increasingly used. In addition, the long distance $\pm$500 kV HVDC andback-to-back systems are also inplace.
Both inter-state aswell asintra-state transmission networks have seen rapid growth over the last two decades and have established a robust system mainly comprising 400kV/765kV AC and
±500kVHVDCaspartofthenationalgridtofacilitate widespread reach of power across the country.Till 2013, the Indian power system comprised two grids atnationallevelviz.,NEWgrid(capacity169GW), which synchronously interconnected NR, ER, WR and NER grids, and Southern Grid (56 GW), with over4000MWasynchronousinterconnectionthrough HVDC lines between these two grids. In a recent majordevelopment,the765kVsinglecircuitSolapur- Raichur transmission line was synchronized on 31 December2013midnightanditconnectedtheNEW grid tothe southern power grid. With the synchronization of the Solapur-Raichur line, the southernstatesaresettobenefitbywayofincreased power import as it would obtain power from the power-surplus regions andstates.
The backbone transmission system in India mainlyoccursthrough400kVand765kVACnetwork withapproximately1,54,593circuitkm(ckm)ofline length and 3,13,922 MVA transformation capacity. Thesearesupportedbyabout1,49,412ckmof220kV transmission network with 2,68,678 MVA transformationcapacity.Inaddition,$\pm$500kV,1500/ 2500MW long distance HVDC (4 nos.) systems traverseabout9500circuitkmwith13,500MWpower transfer capacity including 4 nos. HVDC back-to- back interconnecting links. Details of existing transmission network (220kV & above) in circuit kilometersownedbystate/private/centralsectorsare providedinTable1(CEAReport,March2015).
Forthetransmissioninfrastructureatthecentral level or Inter State Transmission System (ISTS), POWERGRID is

responsible for its development as wellasOperationandMaintenance(O&M).Itowns andoperatesabout1,15,637ckmoftransmissionline at 400kV/765kV level, 192 nos. Extra High Voltage (EHV) substations and HVDC stations with about 2,31,709MVA transformationcapacity

Table 1: Present Status of 220 kV and above Voltage Transmission System in India (CEA Report, 2015) (as on March 2015)

S.No.	Line/station	Central sector	State sector	JV/Pvt	Total
Transmission line (ckm) Voltage Level					
1	765kV	15810	840	1994	18644
2	400kV	82786	40394	12769	135949
3	220kV	10582	137932	898	149412
4	±500kVHVDC	5948	1504	1980	9432
Substation (MVA)					
1	765kV	100500	9000	12000	121500
2	400kV	99175	92617	630	192422
3	220kV	8176	258935	1567	268678
4	±500 kVHVDC	9500	1500	2500	13500

(POWERGRID website). It has a plan to develop additionalabout66,000ckmtransmissionlinemainly at 400 kV and 765 kV levels and more than 90 substationswithabout1,50,000MVAtransformation capacity during 12thplan.(http://www.cea.nic.in/more_upload/conclave/23.pdf)

Allthefiveregionsareinterconnectedthrough the National Grid comprising the hybridAC/HVDC systemthroughtheISTSsystem.Recognizingtheneed fordevelopmentofastrongNationalGrid,thrustwas giventoenhancetheinterregionalcapacityinaphased manner.Thetotalinter-regionaltransmissioncapacity at present is about 46,450MW.

Transmission Losses

Although the overall Transmission and Distribution (T&D)lossesinIndiaarequitehigh,about26%(CEA report, March 2015), the transmission losses are in the range of 3.5% to 4%, which is comparable with other international utilities. The losses are mainly technical in nature, which are intrinsic to power transmission systems and depend on the type of conductorsused,lengthoftransmissionlines,voltage profile,loadinglevelsontheequipment,etc.Broadly, technicallossesarecategorized(Navanietal.,2012)

as (a) resistive losses inherent in all conductors because of the finite electrical resistance of conductors, (b) dielectric losses resulting from the heatingeffectinthedielectricmaterialusedbetween conductorsorconductortoground,and(c)induction and radiation losses that are produced by the electromagneticfieldssurroundingconductors.

Inordertomaintaintransmissionlosseswithin limits, new transmission technologies have been introduced/underimplementationinthecountry(CEA NEP report, 2012), including ±800 kV, 6000 MW HVDC system, 765 kV/1200 kV UHVAC, dynamic reactive compensation through the Flexible ACTransmissionSystem(FACTS)inthegrid.

Majority of the T&D loss occurs in the distributionsector,whichcontainsbothtechnicaland commercialloss.Commerciallossoccursduetopoor metering and return of revenue; whereas, higher technicallossesareattributedtotheunplannedgrowth ofdistributionsector,resultinginverylonglines,lack of adequate reactive power support, lack of informationaboutloadingconditionandpoorhealth ofequipmentleadingtotheirfrequentfailure.Certain measurestoreducethelossesarere-conductoringof lines and reconfiguration of the distribution system, optimal capacitor installation, substation and feeder automation, with features of system and equipment healthmonitoring,loadanddemandsidemanagement, etc.

Future Requirement, Issues and Challenges in Transmission

Generation Capacity Addition Program

Indiahasaninstalledcapacityof268GWasofMarch 2015, the world's fifth largest, yet faces an energy deficitof3.6%andapeakloaddeficitofabout4.7%. The average per capita consumption of electricity is ameager957kWh(2013-14),comparedtotheworld average of about 2,500 kWh. The other comparable countriesintheBRICSgroup(Brazil,Russia,China, andSouthAfricannations)havesignificantlyhigher

percapitaconsumptionthanIndia.Theaverageper- capitaconsumptioninIndiahasgrownsteadilyat4.7% CAGR annually over the last 10 years.
Aspertheestimates,peakdemandinthecountry by 2021-22 and 2031-32 may increase to about 323 GWand592GW,respectively,andthecorresponding installedcapacityrequirementshallbeabout425GW and 778 GW, respectively (IEP report, 2006). Progressively,thegenerationcapacityrequirementby 2031-32isprojectedasshowninFig.3.

Fig. 3: Estimated Generation Capacity Addition (IEP Report, 2006)

Energy Resource Locations
ThenaturalresourcesforelectricitygenerationinIndia are unevenly dispersed and concentrated in a few pockets.HydroresourcesarelocatedintheHimalayan foothillsandinthenorth-easternregion.Coalreserves are concentrated in Jharkhand, Orissa, WestBengal, Chhattisgarh,andpartsofMadhyaPradesh;whereas, lignite is located in Tamil Nadu and Gujarat. North Eastern Region (NER) and Bhutan have vast untappedhydropotentialestimatedtobeabout50,000 MWinNERandabout15,000MWinBhutan.India has some of the largest reserves of coal in the world (approx.267billiontonnes).Coalreservesaremainly located in Orissa, Chhattisgarh, Jharkhand, Maharashtra (Nagpur &Chandrpur), West Bengal (Ranijang),AndhraPradesh(Khammam),andTamil Nadu (Neyveli). Energy resource map of India is shown in Fig.4.
The distribution of energy resources and load centres are extremely unbalanced. The load centres are scattered at far-off places away from resource- richareaslocatedinthenorthernpartofIndia.Recent government initiatives for establishment of special economiczoneshavealsogivenrisetonewpotential load centres. Projects are proposed to be located mostlyatpithead/resourceareas,witheachlocation havingcapacitiesintherangeof5,000-10,000MW.

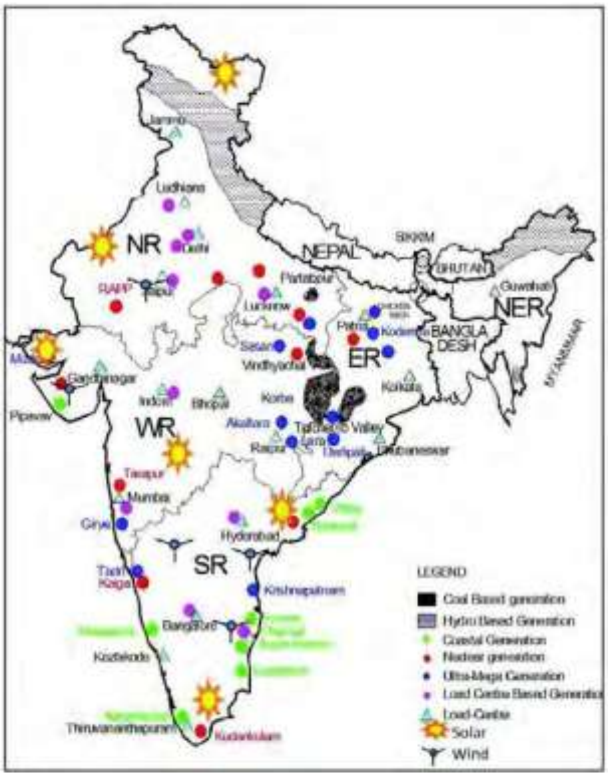

Fig. 4: Energy Resource Map of India (POWERGRID Website http://www.powergridindia.com)

Issues and Challenges in Transmission

Oflate,transmissionsectorisfacingnewchallenges whichhavearisenoutofrapidgrowthoftheelectricity sector coupled with increased requirement ofpower transfer. Pocketed generation resources and wide spreadloadcentersacrossthecountry,coupledwith ROWproblems, necessitate development of high capacity transmission corridors. However, major concernstowardsplanningofsuchcorridorsinclude right-of-way and protection of flora and fauna, Rehabilitation & Resettlement (R&R), flexibility to enhance the transfer capacity in view of uncertainty of generation projects, implementation in different phases,optimizationoftransmissioncostandlosses, non-discriminatoryopenaccesstofacilitateelectricity market, cable manufacturers' to research & develop cables with new type of insulating and conducting materials,integrationoflargescalerenewableenergy sources with the grid in an optimal manner,creation of reliable repairing facilities &development of indigenousmanufacturingcapacity,skilledmanpower for implementation of huge network, and new challenges in operation and maintenance.

Inthecurrentelectricitysupplyregime,various uncertainties are associated with the transmission system development process. Some of the key uncertaintiespushingaparadigmshiftintransmission systemplanningincludeuncertaintiesindevelopment of generation project, no firm beneficiaries at the development stage of generation project due to introductionofcompetitivelybidgenerationtariff,and recovery of investment towards transmission development.

Transmission Plan

There has been a consistent increase in the transmissionnetworkandtransformationcapacityin India.Thisincreaseisinconsonancewiththeincrease ingenerationanddemandofelectricityinthecountry.

Consideringthegenerationcapacityadditionplan for the 12thplan period and commensurate power transfer requirement, transmission line additions of about 1,00,000 ckm, HVDC terminal capacity of 13,000 MW and AC transformation capacity of 2,70,000MVAhasbeenplannedforthe12thPlan.

Table 2 shows the transmission infrastructure addition envisaged in the 12thplan.

Theinter-regionaltransmissioncapacityofall- India grid level is about 46,450 MW which shall be enhanced to more than 66,000 MW by 2017 and 1,26,650MWby2021-22.Fig.5showsthegrowthin interregional capacity by 2021-22 (end of 13thplan).Thegenerationprojectsaremainlyconcentrated insmallpocketsinareassuchaspit-headsinOrissa, Chhattisgarh, Jharkhand or coastal sites with port facilitiesinAndhraPradesh,TamilNaduorhydrosites in Sikkim, etc. To address the ROW issue as well as transfer of bulk power over long distances and keeping in view the long-term power transfer requirement, the development of High Capacity Transmission Corridors (HCTC) comprises 765 kV AC and ±800 kV, 6000 MW HVDC multi-terminal line,whichisbeinglaidstartingfromNERtoNRand otherregions.

These transmission highways would facilitate transfer of power from remotely located bulk power generationprojectstomajorloadcentres.Aschematic diagramof11suchplannedHCTCsisshowninFig. 6.

Table 2: Projected Transmission Network Growth (12th Plan Report, 2012)

	S.No.	Line/station Total	At the end of11thplan	Envisaged addition during12th plan	Expected by end of 12th plan (cumulative)
Transmissionline(ckm)	VoltageLevel				
	1	765kV	5730	27000	32730
	2	400kV	113367	38000	151367
	3	220kV	140164	35000	175164
	4	HVDC	9432	7440	16872
	Substation (MVA)				
	1	765kV	25000	149000	174000
	2	400kV	151027	45000	196027
	3	220kV	223774	76000	299774

4	HVDC (MW)	11200	12750	22500

Based on the progress and development of generationprojectsandtransmissionsystemsduring the12thPlan,onlyabroadassessmentoftransmission capacity addition for the 13thplan can be made considering probable load growth and indicative generationcapacityadditionscenariosforthe13thplan.

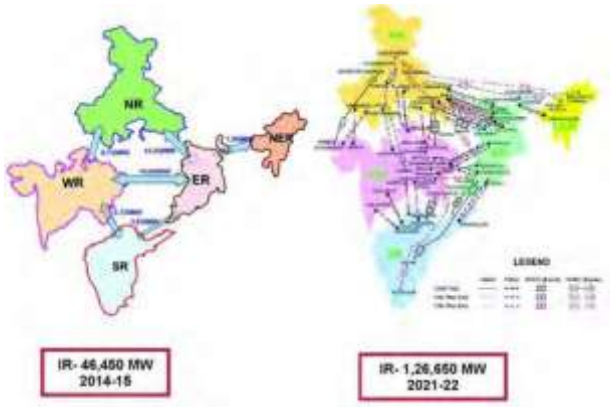

Fig. 5: Growth in Interregional Capacity (CEA Transmission Plan Report, 2014)

Fig. 6: High Capacity Transmission Corridor (NPTI Website, http://www.npti.in)

Accordingly,duringthe13thplanperiod,transmission capacityadditionofabout1,30,000kmand3,00,000 MVA substation transformation capacity have been envisaged.

As part of the evolution of “Green Energy Corridors”,POWERGRIDhas identified transmissionrequirementbothatinter-stateandintra- statelevelsforgridintegrationofenvisagedrenewable capacity addition of the 12thplan (Green Energy CorridorReport,2012).Toaddresstheintermittency andvariabilitycharacteristicsofrenewablegeneration, other control infrastructures such as forecasting of renewable generation and demand, real time measurement/monitoring through synchrophasortechnology, flexible generation, ancillary reserves, demand-sideanddemandresponsemanagementand energy storage, establishment of Renewable Energy Management Centres (REMC) are alsoidentified.

New Technologies in Power Transmission

Transmissionsectorhasconsistentlyadoptedrelevant globaltrendstosupportsustainablegrowthintheIndian power sector. The increasing maturity of thesector
is evidenced by adoption and indigenization of new technologiesacrossthepowertransmissionsectorin general and power sector, inparticular.

Transmissionutilitiesarefocusingoninnovation fordevelopmentofnewtransmissiontechnologiesand seamlessintegrationintheIndiancontext.Inorderto meet the growing power transfer requirement with increased inter-state power transfer requirementand addressing the associated challenges, atwo-pronged approach has been adopted on the technology front. Inthefirstapproach,capacityandreliabilityofexisting transmission infrastructure is enhanced using new technologies. In this direction, many emerging technologies are already integrated into the transmission system such as FACTS devices (Hingoraniand Gyugyi, 2000), e.g. Static VAR compensator (SVC), Thyristor Controlled Series Capacitors (TCSC), Fixed Series Compensation (FSC),reconductoringoftransmissionlineswithhigher capacity conductors,etc.

Inthesecondapproach,newsystemsarebeing designedkeepingthelong-termperspectiveutilizing the latest state-of-the-art technologies. In this direction, new technologies such as high capacity 765kV transmission system (765kV double circuit lines),±800kV6000MWHVDCand1200kVUHV
ACtechnologies, gas insulated substation (compaction), substation automation, compact towers, High Temperature Low Sag (HTLS) conductor, etc. are introduced in addition to existing technical developments.

The country is also establishing the world's highesttransmissionvoltagelevelof1200kVUHV-ACwiththeestablishmentofanationalteststationat BinainMadhyaPradeshin2012.Thistechnologyhas been fully developed indigenously with the collaborativeeffortof35Indianmanufacturersunder Public Private Partnership(PPP).

Further, the country's first ±800 kV HVDC multi-terminal transmission system for bulk power transmission from BiswanathChariali, in the north- eastern region to Agra in the northern region, about 2000 km, is also under implementation and upon completion, this system will be among the world's

longest±800kV HVDC multi-terminal system with power transfer capacity of 6000-8000MW.

To facilitate safe, secure and reliableoperation of the large grid so as to avoid frequent outages throughopeningsoflinesduetoovervoltage,which was otherwise found to weaken the grid under emergency situation (Report on grid disturbance in July2012inIndia),andalsoprovidingvoltagesupport duringvariousoperatingconditionsundersteadystate anddynamicconditions,installationofsuitablestatic and dynamic reactive compensation are essential. Staticcompensationisprovidedintheformofabus/ linereactor,whiledynamiccompensationisachieved throughSVC/STATCOMs.Inthisdirection,16SVC/ STATCOMs are now planned at various strategic locations among all regions to meet the dynamic reactiverequirement.

Withscarcelandavailability,thereisagrowing need for reduction of land use for setting up of transmissionsystems,particularlyinmetros,hillyand other urban areas. Gas Insulated Substations (GIS), which require less space (about 80% reduction), i.e. 5-6 acres as compared to conventional substation which generally requires an area of 30-40 acres. A number of 400 kV GIS substations are established and many more are under implementationincluding those of 765 kV level. In special areas, compact towers such as delta configuration, narrow-based tower, etc., which reduce the space occupied by the towerbase,arebeingused.Inthisdirection,765kV tower with delta configuration and 400 kV pole structure are quite useful and are beingadopted.

To meet various emerging requirements such as achieving controllability/flexibility at grid level, integration of large scale renewable necessitates adoption of other state-of-the-art emerging technologiessuchasVoltageSourceConverter(VSC) based HVDC technology, energy storage technologies,etc.

To improve the efficiency of overall grid management in open electricity market regime, enhancedsituationalawareness,controlatthecontrol centres, and implementation of synchrophasortechnology have been planned for widearea
monitoringofstateandcentralgridsthroughplacement ofPhasorMeasurementUnits(PMUs)atallHVDCs, 400 kV and above substations/generating stations, PDCs (PhasorData Concentrators) at strategic locations,alongwithrequiredanalyticsbasedonPMU measurements such as the Unified Real Time Dynamic State Measurement(URTDSM)system.

Smart Transmission Grid UsingSynchro-phasorTechnology

TheexistingSCADA/EMS,asshowninFig.7,utilizes the Remote Terminal Units (RTUs) for measuring thevoltageandcurrentmagnitudes.Italsomeasures powerflowsinthelines.Typically,theRTUsprovide measurements at a refresh rate of 2-10 s, which are time skewed. Preprocessing of the data, collected from the RTUs, is carried out at the control centre, which includes the processing of bad data, and carrying out the state estimation. These functions collectivelyresultinestimationofthestates,atatypical time interval of 5-10 min. Hence, theSCADA/EMS issuitableformonitoringthesystemunderthesteady state,butisnotsuitableforobservingthesystemunder transientsordynamicconditions.

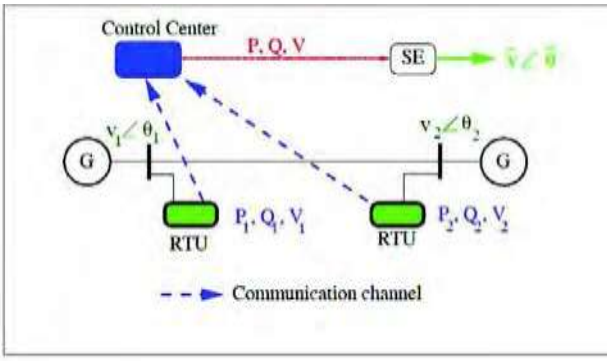

Fig. 7: Typical Conventional SCADA system

WiththedevelopmentofPMU-basedWideArea Monitoring System (WAMS), (Phadke and Thorpe, 2008), as shown in Fig. 8, which utilizes the time- synchronizing pulse (with an accuracy of one microsecond) from the Global Positioning System (GPS), it is possible to measure both the magnitude andthephasorangleofthebusvoltagesinthepower systems.PMUtypicallyprovidesphasorinformation onceinoneortwocycles.Thisfastrefreshingrate

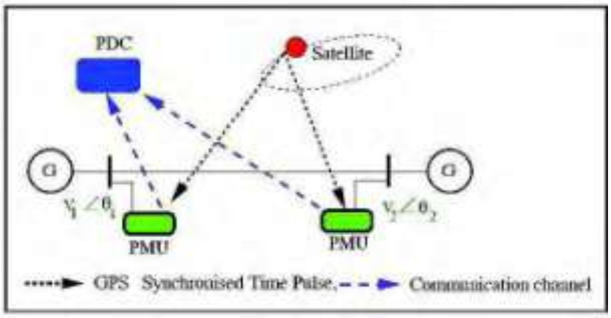

Fig. 8: Typical Wide Area Monitoring and Control System

of PMUs enables them to capture the system states duringtransientconditions.Thedatameasuredfrom the PMU are sent to PhasorData Concentrator (PDC) by utilizing the wideband communication channels such as fibre optic channels. These measurements can further be utilized to take some fast control action, to ensure the stable operation of the powersystem.

Mostoftheutilitiesacrosstheworldareadopting Smart Grid technologies (Smart Grid report, DOE website; NIST report, 2012) to improve the overall operational and energy efficiency, customer satisfaction,securityofthesystemandadoptgreener technology.Someofthebuildingblocksofsmartgrid are advance metering and communication, which includessmartmeters,wideareamonitoringsystem; substation and distribution automation along with distribution and operation management software; renewableintegration;utilityenterpriseapplications; andsystemintegration.Thesmartgridwillhavedistinct features such as self-healing to correct problems early; interactive with consumers and markets; optimized to make best use of resources; predictive to prevent emergencies; distributed assets and information; integrated merging all critical information; and more secure from threats from all system and externalhazards.

Attransmissionlevel,synchrophasortechnology basedwideareamonitoringandcontrolsystemforms an important part of the smart grid. Its importance hasbeenrealizedinunderstandingandanalyzingthe griddisturbanceincidentsinJuly2012(Reportongrid disturbanceinJuly2012inIndia),evenwiththedata of only few PMU measurements deployed at pilot level.

Fig.9showsatypicalblockdiagramofaPMU. The GPS receiver provides two signals, a periodic pulse train at a rate of one pulse per millisecond (1kPPS),andtheInterRangeInstrumentationGroup time code format B (IRIG-B) signal, which is a periodic pulse train at the rate of one time mark per second.The1kPPSsignalisutilizedbythesampling clock to get synchronized with the GPS clock, whereas,theIRIG-Bsignalprovidesthetimetagfor the estimated phasors. The analogue voltage and current signals obtained from the secondary side of thepotentialandthecurrenttransformers,respectively, are preprocessed by an anti-aliasing filter toremove the presence of alias of the signals from the reconstructedsignal.Theanaloguetodigitalconverter samples the preprocessed analogue data, which are further utilized by the microprocessor-based phasorestimator.

The estimated phasors are finally sent to the PDC using the IEEE C37.118 data format (IEEE C37.118.1, 2011; IEEE C37.118.2,2011).

Synchrophasortechnology based Wide-Area Monitoring, Protection, and Control System (WAMPCS) can be effectively utilized for system- widemonitoring,coordinatedrealtimeprotectionand control functions required to counteract the propagation of any major disturbances in the power system.PMUisoneofthemostvitalelementsofthe WAMPC system. PMU reports time-tagged voltage and current phasors required for the dynamic monitoring functions at a much faster rate than the conventional Supervisory Control and Data Acquisition/Energy Management System (SCADA/ EMS).WithrelativelyhighercostofPMUsason

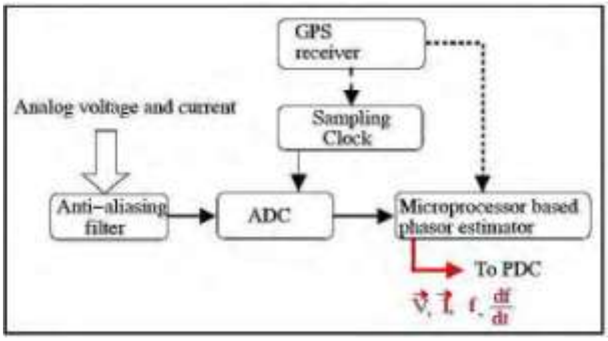

Fig. 9: Typical Block diagram of a PMU

date, these have to be optimally placed to make the systemobservable(Sodhietal.,2010a;Sodhietal., 2011). Utilizing these dynamic measurements, the WAMPCsystem addressesthe automated emergencycontrolfunctionsforvariousinstabilities suchastransient,frequencyandvoltageinstabilities. As the conventional protective systems are decentralized and are non-adaptive in nature, a prerequisiteforimplementingtheWAMPCSscheme istomaketheprotectiverelayingschemesadaptive. Various possible applications of the synchrophasor- based WAMPCS are asfollowing.

Phasor-assisted state estimation (Sodhiet al., 2010b)
- Dynamic phasor estimation (Banerjee and Srivastava, 2012)
- Machine rotor angle estimation using phasor measurements for transient stabilityprediction (Tripathyet al.,2010)
- WAMS-based critical mode identification for small signal stability assessment and control (Tripathyet al.,2011)
- Synchrophasor-based voltage stability assessment (Sodhiet al., 2012)
- Optimal frequency and voltage stability based load shedding (Seethalekshmiet al., 2011a)
- Wide area measurement based adaptive distanceprotection(Seethalekshmietal.,2011b; Seethalekshmiet
- al.,2012)

Modelvalidationandwideareacontrol(Padhy
- et al., 2012)

Some of the above analytics are being developed in-house for implementation in the URTDSM system in India.

Role of Smart Grid Technology in Preventing Major Grid Disturbances

Inanintegratedelectricitygrid,thepowersystemsin different regions are interconnected and very often an incident initiated in one region may lead to a disturbanceinotherregionalso.Griddisturbancemay result in a blackout, which refers to the total loss of power to an area and is the most severe form of the power outage that can occur. Outages may lastfrom a few minutes to a few hours/days depending on the natureoftheblackout,configurationoftheelectrical grid,systemrestorationtime,etc.Someofthemajor blackout incidents across the world (as also listedin http://en.wikipedia.org/wiki/List_of_power_ outages) are asfollowing.

- 1965 US blackout on 9 November 1965 that affected30millionpeople.
- 1999SouthernBrazilblackouton11March1999 thataffected97millionpeople.
- 2003NortheastblackoutintheUSandCanada on 14-15 August 2003 that affected 55million people.
- 2003Italyblackouton28September2003that affected55millionpeopleinItaly,Switzerland, Austria, Slovenia andCroatia.
- 2005Java-Baliblackouton18August2005that affected100millionpeople.
- 2009 Brazil and Paraguay blackout on 10-11 November,2009,thataffected87millionpeople.
- 2012 Indian blackout on 30-31 July 2012 that affected670millionpeople.

The Indian blackout on 30 and 31 July 2012 is considered to be the most severe in terms of thenumberofpeopleaffected.Itcausedthelossofpower supplyforabout14hinNorthIndiaon30July2012 andforabout5-8htheinnorthern,easternandnorth- easternregionsofthecountryon31July2012.These incidents resulted in a loss of a total load of 36,000 MW on 30 July and 48,000 MW on 31 July respectively,asgivenintheenquirycommitteereport (Report on grid disturbance in July 2012 in India). These incidents not only paralyse the life of people affected by the blackout, but also result in huge loss ofrevenue.

Mostofthegriddisturbanceshavebeeninitiated under heavy system loading condition, triggered by the outage of critical line(s), due to naturalcalamity

or faults, and lack of information and control. Some of the major causes observed in various incidents acrosstheworldincludelackofsituationalawareness andrealtimemonitoringtools,inadequateearlysecurity assessment/warningsystem,unintendedoperationof theprotection/impropercoordinationofcontrolactions, lack of enough reactive compensation, and human error&gridindiscipline.

Continuouslargecapacityadditionandexpansion of the grid through increasing interconnections lead to increasing complexity in its management and operation.Openelectricitymarket,widevariationin generationaswellasdemandondaily/seasonalbasis, and increasing penetration level of renewable generation, etc. add to the complexity of the grid management.Maintainingsafety,securityandstability of such a large grid is posing greater challenges. Hence, it is important to know the dynamic state of the grid in real time to assess angular, voltage and frequencystabilityofthesystem;amountofincrease in power transfer that can take place at different instances on various transmission elements; initiate controlandregulationofpowerflowtomaintaingrid under intact condition; and initiate RemedialAction Scheme(RAS) and System Integrated Protection Scheme(SIPS)intheeventofseverecontingencyor likelycondition,whichmayleadtogriddisturbances, to take correctiveactions.

Theaboveaspectscallforseamlessintegration of Intelligent/Smart Grid comprising WAMS using synchrophasor measurements provided by PMU at allsubstationsinthegridintegratedwithhighspeed communication medium such as fibre optics, and powerfulcomputingfacilitiesatcontrolcentres,along with RAS, SIPS. This shall facilitatesafety, security andreliabilityinoperationofthelargegridaswellas ensure efficient utilization oftransmission infrastructure.Italsoimprovesvisualization,enhances situationalawarenessandcontrollabilityandensures self-healing features. Smart grid implementation facilitates proper automation, information flow and datamanagement,requiredforassessingtheincipient system instability/insecurity condition and initiates emergency control actions to prevent system blackout.

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