GOVERNMENT OF INDI1A
MINISTRY OF POWER
CENTRAL ELECTRICITY AUTHORITY
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No. CEA/ NRC/RA -2014 **Dated 29.09.2014**

Subject: Minutes of the Third Meeting of the Sub Group of National Reliability Council for Electricity (NRCE)

The Minutes of the Third Meeting of the Sub Group of National Reliability Council for Electricity (NRCE) held on 08.09.2014, in the NRPC, New Delhi is enclosed for kind information and necessary action please.

Encl: as above

P. Batra 29/9/2014

(Pankaj Batra)
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Minutes of the 3rd Meeting of the Sub Group of National Reliability Council for Electricity (NRCE)

The 3rd Meeting of the Sub Group of National Reliability Council for Electricity (NRCE), was held at NRPC, Katwaria Saria, New Delhi, at 2.30 pm on 08.09.2014 to discuss the methodology and modalities of calculation of calculation of Total Transfer Capability (TTC), Available Transfer Capability (ATC) and Transmission Reliability Margin (TRM) between Northern and Western region and between Western and Southern region, besides other matters. The list of participants is at Annexure - I.

2. The agenda of the meeting was to specifically study the inter-regional constraints between Northern and Western Regions and between Western and Southern Regions, used for calculation of TTC, ATC and TRM between the above Regions, besides other matters. The constraints for Eastern and North-Eastern Regions were also discussed.

3. Initially, the constraints for Eastern and North-Eastern Regions were discussed. Member Secretary, ERPC stated that there was a constraint to export power to the Southern Region. POSOCO was asked to explain the problem with suggestions. POSOCO showed the constraints with the help of an All-India map using a snapshot from SCADA. He stated that the constraints kept shifting with passage of time and differing accompanying network topologies. The details of discussions w.r.t constraints for power transfer from Eastern to Southern Region is given at Annexure-II. It would be seen that the constraints are presently due to the intra-regional line 400 KV Jeypore-Gazuwaka on account of n-1 contingency, which leads to bus voltage of Gazuwaka East dropping below 380 KV, whenever power transfer from HVDC back-to-back link at Gazuwaka exceeds 650-700 MW. This would be resolved when 400 KV Talcher-Berhampur (Odisha) – Gazuwaka D/C line is commissioned. This line has been delayed due to litigation. The matter is with Hon’ble Supreme Court.

Another aspect was the low loading on 400 kV Anugul-Bolangir-Jeypore section vis-à-vis 400 kV Rengali-Indravathi-Jeypore section, the two lines converging at

Jeypore, leading to FSC on the former viz. Bolangir-Jeypore section getting bypassed under normal conditions. So when there was a tripping on 400 kV Indravati-Jeypore, which is normally heavily loaded, the power flow increased on Anugul-Bolangir-Jeypore line. The increased loading and long distance between Angul and Jeypore led to low voltages at Jeypore. It was intimated by M/s Powergrid that the FSC on Bolangir-Jeypore section automatically get bypassed when the loading on the line drops below 10% of the full load, the power required for its auxiliary consumption. After that when the voltage goes down and it is felt that FSCs are required to be put in service, they need to be manually switched on. On query of whether FSCs can be automatically switched on when system voltage goes down (which in turn can enhance the power flow), CTU informed that they will check and inform accordingly. It was stated by Chairperson, sub-Group, that the feasibility of using the auto insertion of the FSC may be explored, if available. It was later informed that there is a provision of auto insertion.

Further, during winter season (low hydro condition) and outage/tripping of one/more units in NTPC Talcher STPS, constraints are experienced for exporting power to SR (above 700 MW) through Gazuwaka due to overloading problem in existing single circuit of 220 kV Jeypore- Jaynagar D/C line of OPTCL. The 2nd circuit of the line is under construction and is expected by Jan 2015, which may reduce the problem.

Chairperson, sub-Group pointed out that proper transmission planning/execution plays a role in ensuring operational reliability of the grid. FACTS devices like phase shifters should be used to transfer power from heavily loaded lines to lightly loaded lines for optimum utilization of existing assets. The phase shifters can be shifted, whenever the constraint shifts, instead of building new transmission lines, if possible, which may not be required at a later stage, since lines, once erected, cannot be shifted, in case they get unloaded at a future period of time.

4. Chairperson sub-group NRCE then asked Member Secretary, ERPC, to explain the constraints for transfer of power between Eastern Region (ER) and North-Eastern Region (NER), since NER is only connected to ER. Member Secretary, ERPC, stated that the constraint was mainly during winter, for transfer of power from Eastern to North-Eastern Region, when the hydro generation in the NER and Bhutan gets depleted. POSOCO stated that the constraint is due to constraint in

the Intra-regional system of Eastern Region i.e. 400 KV Farakka-Malda D/C line. Another intra-regional constraint pointed out was 400 KV Maithon RB – Maithon D/C line, within Eastern Region, which is a short line of about 31 Km. Chairperson, sub-Group asked POWERGRID to explore the possibility of adding another circuit in parallel with this circuit, which could be done quickly, since this was a short line, keeping in view the overall transmission system development. The details of other discussions on this corridor are given at Annexure –III.

5. Next, the transfer between Western and Northern Regions was discussed. It was stated by POSOCO that the constraint for TTC/ATC calculation was based on the setting of the Special Protection Scheme (SPS) on the two Agra-Gwalior 765 KV S/C lines (quad conductor), which was set at 1250 MW for each line. He stated that in case one line trips, the loading on the other line would be about 1.85 times the antecedent loading, which would be about 3000 MW, if the SPS was not available. This is based on the apprehension that in case the second circuit also trips, it would lead to a situation of heavy power flowing to northern region through the eastern region, which would result in tripping of the lines in this path on power swing indications, due to long distance of flow, which led to grid disturbances on 30th and 31st July 2012. It was stated by POSOCO that there was not much difference between the July 2012 situation and the present situation. Chairperson sub-group, NRCE stated that there was a difference between July 2012 and the present situation, since one line of Bina-Gwalior 765 KV (at that time being operated at 400 kV) and Zerda-Kankroli 400 kV S/C line were under outage at that time and also there was no SPS present at that time. Moreover, since this is a critical line, a redundant SPS could be provided with separate CT input, separate communication channel and separate loads for load reduction, but the SPS of which should be set in accordance with tripping of one circuit of Gwalior-Agra 765 KV line, rather than loading of the line. It was decided that this would be put up to NRCE for vetting.

6. POSOCO mentioned that in the Northern-Western corridor, power flowed from Gwalior (Madhya Pradesh - WR) to Agra (UP - NR) and there was a return flow from Kankroli (in Rajasthan- NR) to Zerda (in Gujarat-WR) on the 400 KV Zerda-Kankroli D/C line. Chairperson, sub-Group again emphasised the importance of using FACTS devices for correcting this situation, if possible.

7. The TTC, ATC and TRM between the Western Region and Southern Region was then discussed. POSOCO pointed out that the constraints were in the intra-regional lines, 400 KV Wardha-Parli-Sholapur line (within Western Region) and 400 KV Gooty-Neelamangla/ Gooty- Somanahalli lines (within Southern Region). The 400 KV Wardha-Parli-Sholapur line (within Western Region) was the limiting constraint. In addition, there was constraint in the S1-S2 corridor, within Southern Region, which was already discussed in the earlier meeting. This was concurred by SRPC.

In addition to Kolhapur-Narendra D/C line between Western and Southern Regions, under construction, many new lines to Southern Region from Chhattisgarh have been planned. (765 kV Wardha-Hyderabad D/C, 765 kV Warora Pool-Warangal D/C etc.). These lines would offload 765 kV Sholapur-Raichur line to a great extent. In fact in the recent Standing Committee meeting on Transmission Planning on 31st July 2014, phase shifters have been proposed for loading the Sholapur-Raichur optimally by diverting more power on this line.

8. Chairperson sub-Group mentioned that, in general, since power flow fluctuates in the tie-lines, the SPS, which is used for preventing thermal overloading of the line, should not operate instantaneously but with a time delay, considering the emergency rating. POSOCO mentioned that the emergency ratings of 110% have been provided in the CEA transmission planning criteria and short-term overloads may be limited to that. Chairperson, Sub-group, NRCE pointed out that the emergency ratings considered in the CEA transmission planning criteria were for planning purpose only, as mentioned in the document. He stated that operational emergency ratings are much higher. He circulated a technical paper for emergency loading of transmission lines, including old transmission lines, where emergency loading of about 140% has been allowed for half-an-hour for new transmission lines and 5 minutes for old lines. This is based on temperature rise of conductors using the IEEE 738-2006 formula, which takes into account heat gain due to solar irradiation and ac resistance and heat loss due to radiation and convection. A copy of the paper is attached at Annexure - IV. He stated that this should be used so that there are no frequent trippings due to operation of SPS, and trippings take place only

when warranted. It was stated that the time delay on the SPS on Gwalior-Agra 765 KV line was 10 seconds. A copy of the flow over 24 hours on one circuit of Gwalior-Agra 765 KV line, as well as the total power flow from Western to Northern Region, provided, as requested, by POSOCO, is shown in Annexure – V.

9. POSOCO stated that in view of certain protection systems being unreliable and no reserves being available, the NRCE may issue guidelines taking this into account. Chairperson, NRCE, Sub-group stated that safety and security of the grid was paramount. It would be ensured that power is transferred to the extent possible in a reliable manner.

10. Summing up, the following decisions were taken:-

i. Feasibility of using the auto insertion of the FSC in on Bolangir-Jeypore section in Eastern Region may be explored.

ii. FACTS devices like phase shifters should be used to transfer power from heavily loaded lines to lightly loaded lines in a corridor, for optimum utilization of existing assets.

iii. The possibility of adding another circuit in parallel with 400 KV Maithon RB – Maithon D/C line, within Eastern Region, may be explored, keeping in view the overall transmission system development

iv. Since power flow fluctuates in the tie-lines, the SPS, which is used for preventing thermal overloading of the tie-line, should not operate instantaneously but with a time delay, considering the operational emergency rating.

v. It was decided that the SPS of Gwalior-Agra 765 KV D/C line, should be set in accordance with tripping of one circuit of Gwalior-Agra 765 KV line, rather than loading of the line. This would be put up to NRCE for vetting. Moreover, since this is a critical line, a redundant SPS could be provided with separate

CT input, separate communication channel and separate loads for load reduction, but

Annexure - II

Details of discussions w.r.t constraints for power transfer from Eastern to Southern Region

1) POSOCO informed that the chronological order of constraint in East to South transfer had to be appreciated. In 2010, it used to be 400 kV Vijaywada-Nellore D/C in Southern Region due to heavy gas generation in Vemagiri complex and low voltages in Chennai area. This placed a constraint in power transfer from East to South over Gazuwaka HVDC link. Subsequently in 2011, with the reduction in gas generation and coming up of MEPL/SEPL and Vallur generation, closer to Chennai in SR, the constraints within Southern Region abated. The constraint then shifted to 400 kV Rourkela to Talcher D/C in 2011-2013 due to reduction in Talcher generation and South Odisha hydro. This constraint abated with the commissioning of 400 kV Jamshedpur-Baripada D/C section between June 2013 to Aug 2013.

2) The present constraint in ER-SR transfer is n-1 contingency of 400 kV Jeypore-Gazuwaka one circuit outage leading to bus voltage of Gazuwaka East dropping below 380 kV. This was the situation whenever the power order on Gazuwaka exceeded 650-700 MW. The primary reason for this was the low fault level at Gazuwaka East bus as the nearest generator was at Talcher, particularly when South Odisha hydro generation was minimal or nil. Whenever Odisha hydro generation was high, 220 kV Jayanagar-Jeypore D/C section became N-1 insecure. Further 220 kV Indravathi-Therubali one D/C line was out due to tower collapse and recently during the evening peak hours there was a major loss of generation/load in South Odisha.

3) Another aspect was the low loading on 400 kV Anugul-Bolangir-Jeypore section vis-à-vis 400 kV Rengali-Indravathi-Jeypore section, leading to FSC on the former viz. Bolangir-Jeypore section getting bypassed under normal conditions. So when there was a tripping on 400 kV Indravati-Jeypore, the long distance between Angul and Jeypore led to low voltages at Jeypore.

4) On suggestions for mitigation of the above problems, POSOCO informed that the network augmentation at Gazuwaka was the main issue and the 400 kV Talcher-Berhampur (Odisha)-Gazuwaka D/C line (to be constructed under TBCB) was delayed.

5) Problems similar to Gazuwaka were experienced at Bheramara HVDC connection to Bangladesh as again the fault level here was low. Tripping of 400 kV Farakka-Behrampur section led to low voltages at Jeerat/Behrampur. Any tripping in West Bengal system led to curtailment of Bangladesh transactions. High loading on 400 kV Farakka-Behrampur had led to several outages taken on the section for attending to hot spot/jumper tightening.

Annexure - III

Details of discussions w.r.t constraints for power transfer from Eastern to North-Eastern Region

1) On the ER-NER transfers, the constraints on 400 kV Farakka-Malda D/C was highlighted, particularly during winter. Re-conductoring this section was under implementation. Even after 400 kV Purnea-Biharsharif D/C was commissioned last Sep 2013, the transfers were from Purnea to Biharsharif direction during winters, which accentuated the loading on 400 kV Farakka-Malda D/C. It was further informed that during last winter, after further studies such as bus splitting at 220 kV Dalkhola and standing instructions for opening of 400 kV Malda-Purnea D/C one by one in case of any overload on the 400 kV Farakka-Malda section, the ER to NER TTC was enhanced from 500-550 MW to 720 MW. However, with Palatana GPS getting commissioned, there was a need for having more TRM of the order of 280 MW as the intra NER system was quite weak to withstand a 363 MW loss at Palatana.

Application and evaluation of short-term emergency ratings for double-circuit transmission lines

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Application and Evaluation of Short-term Emergency Ratings for Double-circuit Transmission Lines

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Abstract *–Emergency ratings have been introduced for operating transmission lines safely and supplying current capacity efficiently, as well as controlling load flow when occurring line faults. In this paper, short-term emergency ratings are calculated by using thermal equilibrium equation for bared conductors in double-circuit transmission lines. Overhead transmission lines installed in double-circuit have been extensively utilized worldwide to enhance power transmission. Such lines show various advantages in increasing transmission capacity and decreasing power loss as well as being operated flexibly during a contingency. Even when a fault occurs in one circuit, the healthy circuit can supply power continuously during emergency without outage. The utilization of such double-circuit transmission lines during normal and/or emergency operations is described. Maximum normal operating current based on fault duration, maximum allowable temperature of conductor, and thermal line ratings are evaluated. Several performances of dip/clearance affecting short-term emergency rating are also presented.*

Keywords double-circuit transmission lines, short-term emergency rating, thermal line rating.

1. INTRODUCTION

It has become increasingly difficult to build new transmission lines due to the reorganization of power industry, and demand of higher economic management. Many power companies are searching for efficient operation strategies applicable to the present power networks without new investments. Therefore, re-evaluation of available capacity, conductor lifespan and emergency ratings have been taken into account. Consequently, utilities are looking at alternative approaches to up-rate the load capacity (ampacity) for the existing transmission lines [1], [2].

The ampacity of an overhead transmission line is given as a thermal rating of conductor calculated by a specific conductor temperature. In particular, the conductor current for a maximum allowable temperature is defined as static line rating (SLR) [3]. The maximum allowable temperature of conductor is determined based on a specified tensile loss, a suitable dip/clearance margin, or conservative weather conditions [4], [5]. Typically, SLR involves the pre-determination of worst-case weather conditions along the entire line for an extended period of time. This assures that the conductor will not sag below the required safe clearance at any point during the conductor lifespan. On the other hand, dynamic line rating (DLR) is the rating defined as the steady-state load that produces the maximum conductor operating temperature, based on actual loading and weather conditions. Most transmission lines are not designed to carry all the maximum ratings due to contingencies or overloading of the line. Normal operation ratings are usually given below SLR or DLR. Hence there always exists some margin of rating, especially that ratings are increased during a short time interval.

Emergency ratings can be determined by considering both fault duration and limiting temperature/overload rate. Long-term emergency rating (LTER) is the rating through fault durations of several hours; it is based on the steady-state thermal rating of conductor. Short-term emergency rating (STER) is the rating given for the transmission line to operate safely through shorter fault durations [6], [7]. Hence, both the steady-state characteristics and transient response should be considered in the heat-balance equation. Transient ratings cannot be defined as common standard indices. Most power companies have their own standards for emergency actions before any fault may lead to significant accidents such as widespread outages on transmission networks. Transient line rating is defined as a relative concept of SLR, yet it is only given for a constant-time interval. In particular, such emergency ratings are commonly determined by considering several factors such as SLR, annealing characteristics, and conductor lifespan. Thermal performance of conductors should be taken into consideration as a function of time.

Most utilities have been utilizing double-circuit transmission lines (DCTLs) to enhance the reliability and security for power transmission [8], [9]. Transmission lines cannot operate with full load; therefore, normal operating load is always limited below the maximum design load. Outage of a single circuit of DCTL is normally classified as a single contingency and – for such a contingency – the transmission line should be designed to sustain power supply safely, with an emergency rating. For analysis purposes, emergency ratings of DCTLs are discussed.

2. Emergency Ratings of Double-circuit Transmission Lines

2.1 Thermal Line Rating

If the current and temperature of a bare overhead conductor are denoted by I and T_c, respectively, the heat-balance equation is given as [3],

$$mC_p \frac{dT_c}{dt} + [Q_c(T_c) + Q_r(T_c) - I^2 R_{ac}(T_c)] = Q_s \qquad (1)$$

where mC_p in J/m^{o}C is the total heat capacity of conductor, and $R_{ac}(T_c)$ is the AC resistance per unit length in mΩ for the given conductor temperature. Also, $Q_c(T_c)$, $Q_r(T_c)$ and Q_s in W/m^2 are the convective heat-loss, radiated heat-loss, and sun heat, respectively. If the conductor reaches the maximum allowable temperature under specified weather conditions, the line current in the steady-state could be determined using Eq. (1), which is defined as SLR. In general, SLR is given as a constant current that would yield the maximum allowable conductor temperature for specified weather conditions and conductor characteristics with the assumption that the conductor is in thermal equilibrium.

In this research, the conductor is assumed to be Aluminum Conductor Steel Reinforced (ACSR) and its maximum allowable temperature is specified at 90 ^{o}C [10]. The maximum allowable temperatures of ACSR are in the 50–180 ^{o}C range, depending on weather conditions or ground clearance; hence, the thermal rating of any conductor also varies widely [3]. In most utilities SLR sets the allowable current limit under worst weather conditions. Under normal weather conditions, transmission capacity higher than SLR can be transferred through the same transmission line. All line conductors have marginal capacities higher than the specified ratings. In determining the thermal line rating, there are two major limitations; one is to limit the maximum allowable temperature, and the other is to maintain a sufficient ground clearance. The maximum allowable temperature of conductor is normally selected so as to limit the conductor tension-loss due to annealing, or to hold a required ground clearance.

2.2 Double-circuit Transmission Lines

In practice, DCTLs can have different configurations based on the system topology and how they are connected at the two ends of the double circuit line [11]. For example,

- They are not connected to the same bus at either end of the line;
- They are connected to the same bus at only one end of the line; or,
- They are connected to the same bus at each end of the line.

The operation may be different, depending on the system network (loop or radial). Meanwhile, there exist various conditions to be considered. However, the current research is focused only on the analysis and application of short-term line rating, calculated by using transient thermal rating, and DCTL was used as an example transmission line in order to analyze STER performances. For simulation purposes, the following assumptions were made:

(a) The line length is sufficiently short to transfer thermal line rating [1].
(b) At each end, the lines are connected to the same bus [11].

In the present study, it is assumed that two circuits are connected in parallel to the same bus at each end of the line. Associated protection systems are assumed to be installed properly; thus, the healthy circuit operates automatically to carry all loads when one circuit in service breaks down. As a result, one healthy circuit would carry twice the normal operating current before a fault. Therefore, its operating load cannot be preset to maximum allowable load of the utility line.

To guarantee the reliability of power transfer with the assumption that one circuit of DCTL may fail, a maximum operating load per circuit may be limited to half the maximum allowable conductor load and the line can operate safely with one circuit only. However, the load can increase further within any suitable levels to ensure safe power delivery. Determination of maximum load depends on various factors such as conductor type/size, dip margin and tower design, line voltage, generator and main transformer capacity. If the transmission line guarantees sufficient dip margin, its rating may be selected as a higher load level. Most utilities have their own criteria for dip limit and tower design; therefore, the solution for determining maximum load or STER may not be unique even in the case of similar transmission lines.

2.3 Basic Strategy for Emergency Ratings

Emergency ratings are available to prevent overload lines from breaking down or shedding load. Transient characteristics may be different, depending on weather conditions and normal operating load at the beginning of a fault. Circuit breakers at the line ends may operate automatically as soon as the line current exceeds maximum allowable value. However, most power companies use emergency ratings as pre-calculating levels for stable power transfer.

Emergency rating depends on fault duration, and the protection equipment should be designed based on that rating [6], [7], [10]. There are two different methods to represent emergency ratings: (1) after a maximum allowable temperature of conductor is selected under suitable conditions, the corresponding maximum allowable current is provided or, (2) presetting a suitable overload rate, the maximum allowable current can be determined based on this rate. In this research, the first index for emergency rating (i.e., maximum allowable temperature of emergency) is used.

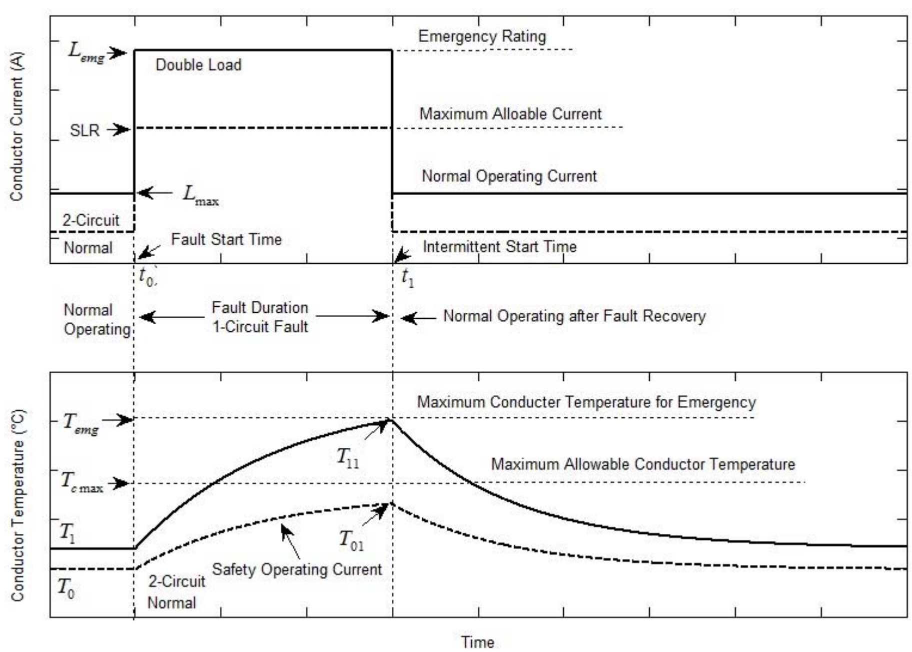

Figure 1. Emergency rating characteristics of DCTL.

In order to illustrate an emergency operation of transmission line, first, one circuit of

DCTL is assumed to be faulted at time t_0. The faulted circuit is disconnected from the line instantaneously, the other circuit can transfer all load automatically during the occurrence of fault. In Figure 1, t_1 is the time at which the protection relay operates. If the normal load of one circuit – before fault – is defined as an initial conductor load, L_0, the healthy circuit must carry double load of $2L_0$. If the fault is eliminated at time t_1, the faulted line recovers to normal operating status and the transmission line transfers the normal load as before. If the line load is to be limited to 50 % of the maximum level according to operation standards, the maximum value of L_0 becomes 50 % of SLR. Assuming L_0 is the maximum normal load per one circuit, the load during the fault is SLR.

From the time the fault starts, conductor temperature begins to rise slowly from T_0. Since the maximum load of the healthy circuit is equal to SLR – which is a value calculated at the maximum allowable conductor temperature of 90 ^oC – the conductor temperature increases towards 90 ^oC. However, the line fault is removed at t_1 before the conductor reaches the maximum temperature, then it starts to decrease with time. As a result, the line can be operated safely without failure of the power line. Most power companies have transmission lines not to exceed their respective emergency ratings according to their own operating rules. Such rating is specified as overload rate or limit-temperature of conductor; however, emergency rating is typically given as a load in amperes.

An emergency duration is assumed to be a finite time interval, t_1, and a maximum allowable temperature for emergency to be T_{emg}, in order to prevent considerable annealing and tension loss of conductor. Hence, conductor temperature should not exceed T_{emg} during the fault. It can be seen that conductor temperature reaches T_{emg} at t_1. Thus, the emergency rating must be determined by considering the transient response of conductor temperature. When adopting emergency rating conditions for DCTL, the maximum load of transmission line must be predetermined. Such operating limits are based on time response, as shown in Figure 1. In DCTL, it is important to specify the maximum operating load, L_{max}, as well as $L_{emg}(= 2L_{max})$. STER should be considered taking into account both the thermal rating and transient characteristic of conductor, whereas LTER would be used as the rating to only restrict thermal rating of conductor.

3. Determination of Emergency Ratings

3.1 Analytical Conditions

To verify emergency rating performances, the DCTL under study is assumed to be a 154 kV transmission line with ACSR 410 mm^2 bundle conductors. Most EHV transmission lines commonly use bundle conductors as phase conductors. However, a phase conductor is assumed to be single – for the simplicity of analysis – and is considered with loads (or ratings) focusing on one circuit of DCTL only. The maximum allowable temperature and its maximum current of ASCR 410 mm^2 conductor are assumed to be 90 ^oC and 848 A, respectively [12].

Generally, the available transmission line capacity is limited by two main factors: the thermal line rating, and the dynamic security rating that relates to the phase-angle difference due to line impedance. Short lines are *thermally limited*, while long lines are *security limited*. The experimental DCTLs under study are assumed to be short lines, only limited by thermal ratings.

3.2 Short-term Emergency and Fault Duration

The normal operating load of DCTL can be determined based on fault duration time and maximum conductor temperature for emergency rating to be allowable within the fault duration. Except for rare special cases such as old transmission lines built with lower dip criteria, the maximum temperature of conductor to specify emergency ratings is normally given as 100 ^{o}C or 120 ^{o}C for ACSR conductors, with maximum allowable temperature of 90 ^{o}C. In the present research 120 ^{o}C is taken into account for STER.

Figure 2 illustrates temperatures and ratings for different fault durations. Through the transient response of ACSR conductor, the initial temperature is pre-determined such that conductor temperature can reach the limit of 120 ^{o}C. The conductor current corresponding to this temperature can then be calculated; it is the maximum operating current of one circuit of DCTL, and the double-load of maximum operating current becomes a STER for the given fault duration. Several performances for short-term durations are summarized in Table I. If a short-term duration is chosen to be 5 minutes, one of the two circuits can allow the normal operating current of 1,724 A where the temperature theoretically reaches 91 ^{o}C, which is not accepted as a practical rating since the maximum continuous temperature of ACSR should not exceed the normal operating temperature.

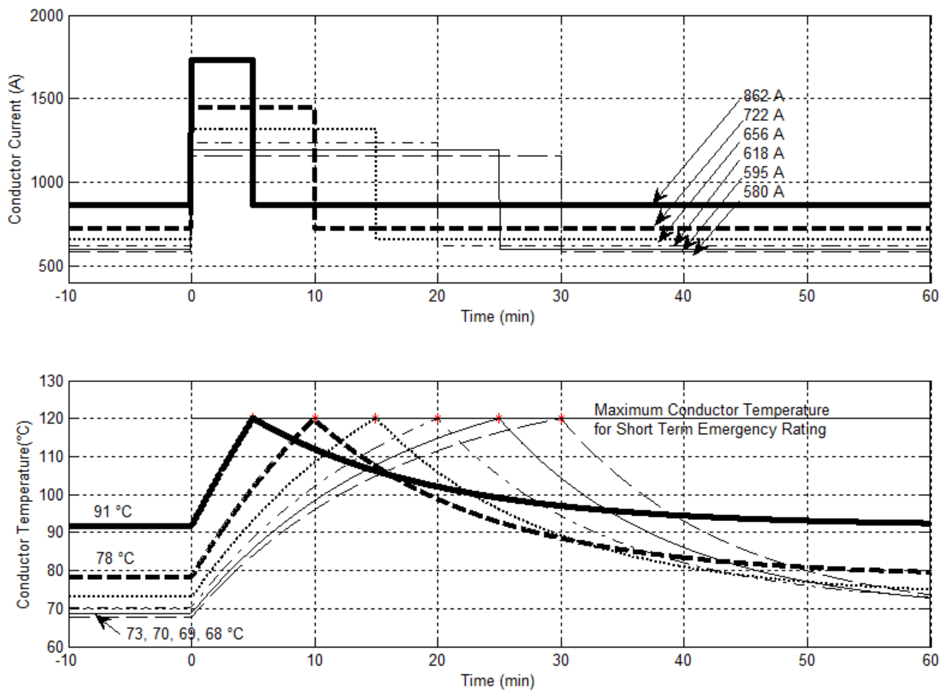

Figure 2. Load performance for different fault durations.

Table I – STER characteristics for different fault durations.

Fault Duration (min)	Normal Operation Rating Temperature (^{o}C)	Maximum STER (A)	Overload Rate (%)

5	91	1,724	203
10	78	1,444	170
15	73	1,312	155
20	70	1,236	146
25	69	1,190	140
30	68	1,160	137

Another limitation to select short-term duration is the dip criterion, which is a very significant key for conductor design temperature to be taken into account. Generally, maximum allowable conductor temperature is the maximum temperature limit to be selected in order to minimize annealing and loss of strength through the conductor life. Meanwhile, the maximum design conductor temperature is a temperature limit to be considered in order to guarantee a required dip when designing a line. Although there are various criteria or rules in designing ground clearance or towers, transmission lines built by several power companies were designed based on the maximum design temperature, 75 ^{o}C [13], [14], and it was applied to transmission lines in KEPCO starting in 1992 [10], [15]. Consequently, the short-term duration of 5 or 10 minutes may be unrealistic, despite showing a larger overload rating. However, in the case of selecting 15-minute duration, the line can carry 155 % load of SLR without violating ground clearance. Finally, DCTL can be available to supply maximum current of 1,312 A for the two circuits, i.e., 656 A per circuit. In other words, it becomes the maximum normal operating current of DCTL under the given duration of 15 minutes for STER. Durations longer than 15 minutes can be used, but the maximum normal rating would be reduced which would limit the transmission line efficiency.

3.3 Old Transmission Lines

There are two important issues to be considered in case of transmission line design; one is to determine a suitable transmission capacity, and the other is to consider a suitable dip/clearance margin. Thermal line rating represents line current which corresponds to the maximum allowable conductor temperature for a particular line without clearance infringements, or significant loss in conductor tensile strength due to annealing [6], [13]. Transmission power has been traditionally limited by conductor thermal capacity defined in terms of SLR, based on a predetermined set of conditions. These conditions are incorporated into the line design to take ground clearance into account. All transmission lines are designed such that an acceptable ground clearance is maintained – at a certain design conductor temperature – according to the construction standards of the time. Thus, unless associated committees have recommended specific regulations, a default temperature of 75 ^{o}C will be used to calculate both normal and emergency ratings of transmission lines [13].

Since the maximum allowable temperature of ACSR is 90 ^{o}C, transmission lines have margins higher than SLR or clearances designed within the design temperature of conductor, 75 ^{o}C. Normally most power utilities design transmission lines to be operated under the maximum conditions. However, in domestic transmission lines, ground clearances are usually required to have higher margins than design levels. As these criteria were established in different times, any specifications determined by such criteria may be unrealistic. Furthermore, there is a limit for the operating temperature or rating, and the maximum allowable temperature for such a transmission line may be restricted to the temperature at which the line can guarantee minimum clearance; sometimes it is selected below the maximum continuous-operating temperature of 90 ^{o}C. In this paper it is defined as the limit-dip conductor temperature (LDCT), e.g., 86 ^{o}C, and it is an estimated temperature by an old design criterion [15].

At the maximum allowable temperature of 86 ^{o}C for LDCT during a fault, some characteristics are summarized in Table II. Results are similar to those listed in Table I at 86 ^{o}C, instead of 120 ^{o}C. As the maximum temperature of conductor of this line is limited to 86 ^{o}C, due to dip margin determined by design criteria, the maximum STER or operating current to be available is more restricted than the current for 120 ^{o}C given in Table I. For LDCT at 86 ^{o}C and 120 ^{o}C temperatures – for 15-minute duration – the maximum STERs are 944 A and 1,312 A, respectively. As a result, the effectiveness of applying STER for DCTL would be reduced, which means that it may be possible for STER to apply to such old transmission line with a lower LDCT. The result implies that the effectiveness will be more limited for such old transmission lines in service. In order for the performances of STER to be improved in old lines, there are several actions to be taken such as increasing the tower height, replacing old conductors by high-temperature, low-sag conductors, or providing sufficient dip/ground clearance. Also, applying the dynamic line rating technique is considered a good strategy [13].

Table II – STER characteristics at limit-dip temperature of 86 ^{o}C.

Fault Duration (min)	Normal Operation Rating Temperature (^{o}C)	Maximum STER (A)	Overload Rate (%)
5	69	1,192	141
10	64	1,026	121
15	62	944	111
20	60	865	106
25	60	868	102
30	59	848	100

3.4 Normal Operating Current Conditions

In practical cases of applying emergency rating, there are various operating rules and related equipment in power systems. Hence, actions to be taken by the line operator during pre-contingency or post-contingency status are preset. When a line load is over LTER but below STER, within 15 minutes, suitable corrective procedures to solve the overloading of transmission line must be available. In general, such corrective steps may be load shedding, voltage reduction, or disconnecting the load [14]. Proper corrective actions can be only `taken when the line fault or contingency is timely detected. For STER applications, it is a crucial key to detect the overload level and its duration period. By way of example, the fault duration is assumed to be 15 minutes and the emergency properties when varying conductor current are taken into consideration. If one circuit is broken at the beginning of fault, the other healthy circuit starts to carry twice the load from that instant, as shown in Figure 3. Conductor temperature at fault time begins to increase slowly until the end time of fault, which is the constant time preset by protection relay. The line automatically sheds the overload to another transmission-line bus, or reduces its rating.

At a normal operating current of 656 A and fault duration set to 15 minutes, the maximum allowable temperature of DCTL can be selected up to 120 ^{o}C, even under worst weather conditions. However, if the line is operating normally with a load of 1,312 A and temperature of 73 ^{o}C, the conductor temperature reaches 120 ^{o}C after 15 minutes. At this time, one circuit load – due to the fault – can be separated from the faulted transmission line to another line.

When protection relays are installed to detect fault time and to set fault duration, the conductor temperature does not increase up to the maximum allowable limit even for STER. For instance, let the initial conductor load be 1,200 A for the two circuits. If a fault occurs on one circuit at time t_1, the temperature of healthy conductor reaches 109 ^{o}C, and the transmission line carries only 600 A of one circuit load while disconnecting the other 600 A load of the faulted circuit. If the protection relay is operated by presetting temperature limits – not by duration – in case of 600 A (or 500 A) for initial operating loads, the time reached will be either 23.7 minutes or infinite, respectively, as given in Table III. Therefore, presetting a fault-clearing time may not be effective which implies that a faulted circuit on DCTL – with up to 500 A per circuit – can be operated without any corrective measures such as STER or LTER. However, the circuit must be designed with maximum operating temperature of 120 ^{o}C, when factors such as annealing and useful life of conductor are taken into consideration. According to analytical results for 500 A per circuit, the circuit may operate safely for such a faulted transmission line without any protection strategies.

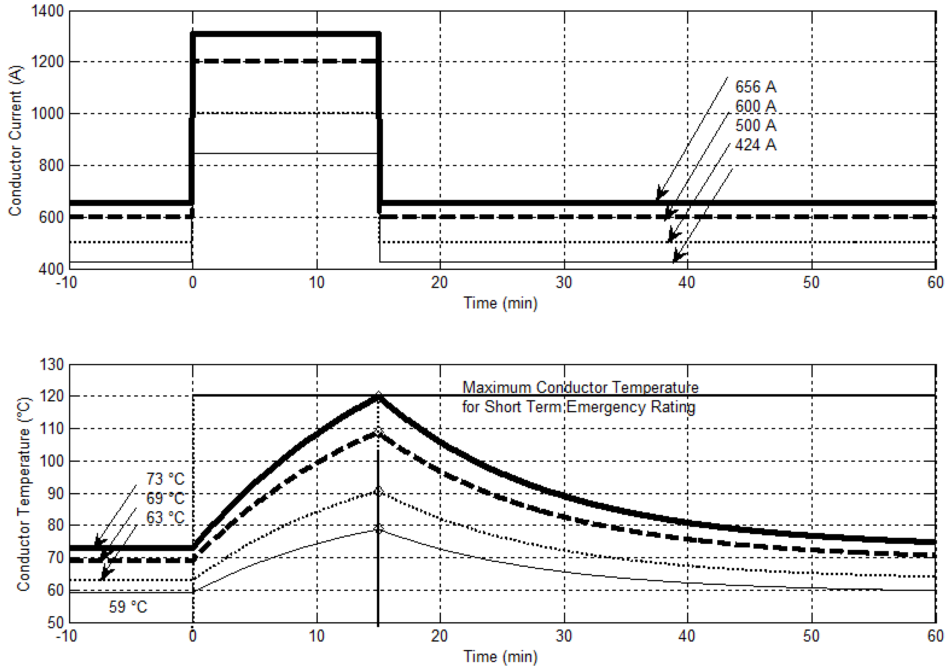

Figure 3. Load and transient characteristics as function of fault duration.

Table III – STER characteristics for different initial loads.

Initial Conductor Load (A)	Initial Conductor Temperature (°C)	Temperature at Final Time t_f (°C)	Time at T_{120} (min)	Overload Rate (%)
424	59	79	∞	100
500	63	91	∞	118
600	69	109	23.7	142
656	73	120	15.0	155

3.5 Fault Examples

In order to demonstrate the performance of emergency rating, an actual DCTL (described in Section 3.1 with its line voltage of 154 kV and ACSR 410 mm^2 bundle conductors) is analyzed. It is assumed that the transmission line was built according to old criterion with a limit-dip temperature of 86 ^{o}C. The maximum operating load is preset at 1,888 A per circuit with bundle conductors, and is applied to STER with a duration of 15 minutes. To estimate the variation of conductor temperature with time, actual ambient temperatures and wind speeds monitored near the substation located at one end of the line were used.

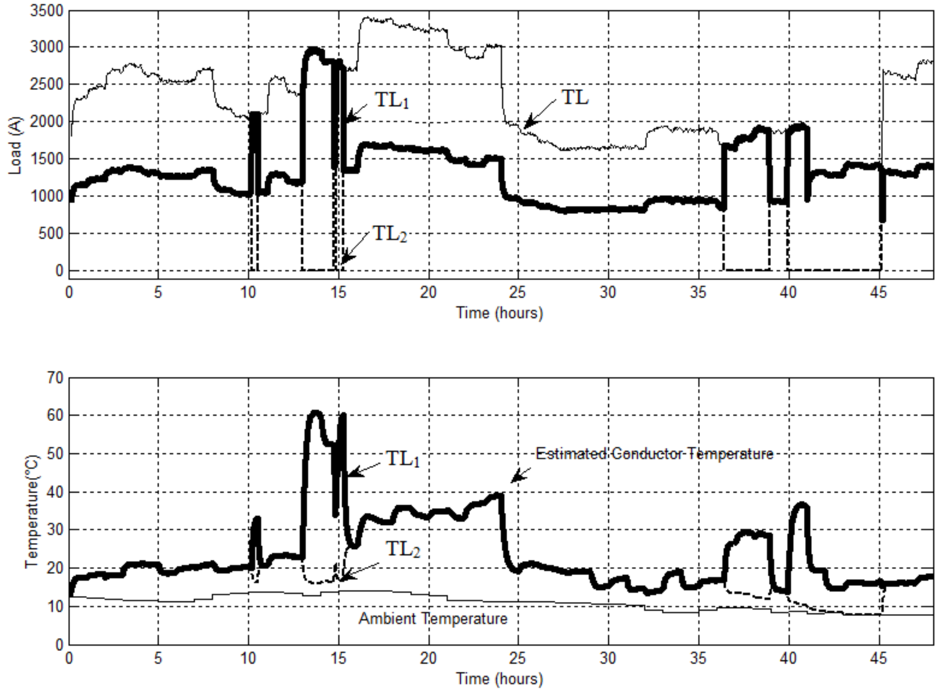

Figure 4. Example of applying STER to DCTL.

For simulation purposes, the two-day DCTL loads are assumed to be of increased levels more than the actually monitored loads, as shown in Figure 4(a), where TL_1 and TL_2 denote load curves of the two circuits, respectively. From the load curve it can be seen that TL_1 operated under normal conditions, while for TL_2 there were several contingencies. During these faults, the healthy circuit TL_1 automatically carried double the load, as it was expected.

Conductor temperature can be estimated based on actual weather conditions, conductor type, load data, and geographic location. Conductor temperatures for TL_1 and TL_2 are calculated, as shown in Figure 4(b). As the time constant for ACSR conductors – when the load is changing – is expected to be approximately 15 minutes, it is known that all contingencies can last beyond the time constant. Therefore, the conductor temperature can reach any equilibrium levels. The first four faults went in progress during daylight, but the latest fault for 40 to 45 hours occurred in the evening. Therefore, TL_2 during the last fault shows the same temperature – the ambient temperature – as time elapses.

TL_1 carries double load over 15 minutes of a short-term emergency; however, its conductor temperature does not exceed the LDCT of 86 ^oC (or the maximum allowable conductor temperature for emergency rating). Therefore, the line can supply power with reliability and safety without violating ground clearance. According to the analytical results in Section 3.3, in such situation the line operates near the maximum operation rating and the temperature of the healthy conductor may reach 86 ^oC within the time period of short-term emergency. However, weather conditions such as ambient temperature and wind speed are not at their worst levels. As a result, the line shows up-rating load more than SLR, despite a short-term emergency.

4. CONCLUSIONS

Double-circuit transmission lines (DCTLs) are used in the present study to apply and evaluate short-term emergency ratings. For a typical DCTL, it is assumed that even when one circuit of the line may become out of service, due to any fault or contingency, the healthy circuit begins to supply power continuously. The emergency rating will be generally used as the limiting rating to identify thermally limited conductors. Therefore, it is very important to determine emergency ratings, fault durations, and allowable temperature limits.

Considering annealing of conductor and its lifespan, a maximum allowable temperature of ACSR conductor can be selected to be 120 ^oC in order to apply a STER to DCTL. When the short-term duration of emergency rating is changed, the conductor current is calculated, which is defined as the maximum operating load of the line under normal operating conditions. Furthermore, an application of STER to some old transmission lines (built according to past design criteria) with a lower dip/ground clearance margin is analyzed. In such transmission lines, maximum conductor temperature could be restricted to a limit-dip temperature, i.e., 86 ^oC. Normal operating current when fault duration was preset and maximum operating current – when varying maximum allowable conductor temperature – are also discussed. The focus was on designing emergency ratings with short-term duration. Both the efficiency and possibility of applying STER to DCTL are presented.

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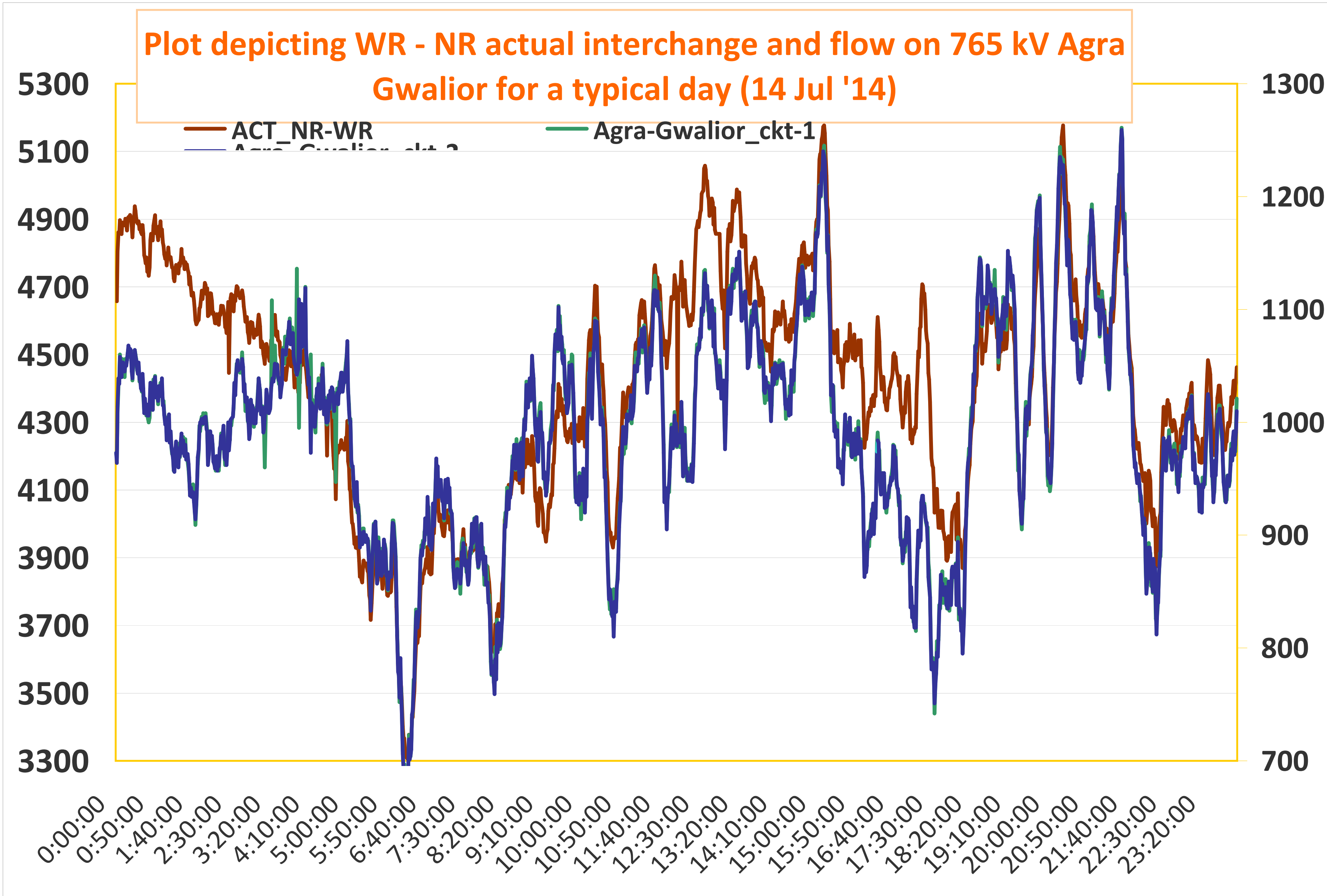

Plot depicting WR - NR actual interchange and flow on 765 kV Agra Gwalior for a typical day (14 Jul '14)
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ANNEXURE-I

ATTENDANCE SHEET

3rd MEETING OF SUB-GROUP (NATIONAL RELIABILITY COUNCIL FOR ELECTRICITY)

AT NRPC ON 08.09.2014

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ATTENDANCE SHEET

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