Voltage Security Constrained Optimal Power Flow considering Smart Transmission Switching Maneuvers

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***Abstract*—To increase the security level and stability of the power systems, high controllability capability is needed. The voltage security margin (VSM) index in power systems can be also affected by various transmission switching (TS) maneuvers. However, one of the major challenges in optimal power flow problems using TS, is that there is no limit to the number of switching on the network over specific periods, thus increasing the probability of a failure occurrence, reducing also the reliability and lifetime of circuit breakers. In this work, a model of optimal power flow (OPF) problem using smart TS concerning the reliability of the CBs to reduce the number of switching and operation costs is presented, formulated with a non-linear function. Thus, a linearization method is implemented to linearize CBs reliability formulation, considering as well locally reactive power compensation devices such as capacitors, allowing more active power flow through the lines to supply more loads. An optimal planning and operation of capacitors can be introduced as another solution to increase the voltage security margin and network loading. The proposed linearized AC power flow model is evaluated in a real case study of the Fars Regional Electric Network in Iran.**

Index Terms*—Capacitors, Circuit breakers, Maneuver, Optimal Power Flow (OPF), Transmission switching (TS), Voltage security margin (VSM).

NOMENCLATURE

A. Indices and Sets

t	Time periods.
g, b, k	Index of generators, buses, and lines, respectively.
l	Number of piecewise linear blocks.
f, r	Elements of the piecewise linearized model of radiation loss.
j	Dummy set for time periods.

B. Variables

q_c	Convection heat losses [MW/m].
$ql_{k,t}$	Heat losses due to lines' power flow [MW/m].
Z^{down}	Objective function.
$P^s_{k,t}, Q^s_{k,t}$	Line active/reactive power flows [p.u].
$PL^s_{k,t}, QL^s_{k,t}$	Line active/reactive power losses [p.u].
$P_{sh_{b,t}}$	Amount of load shedding due to CB failure [p.u].
$Pj_{k,j}, Pc_{k,j}$	Part of load shedding due to CB failure as a function of a binary variable [p.u].
$P^0_{g,t}, Q^0_{g,t}$	Generator active/reactive power [p.u].
$\Delta r^s_{g,t}$	Generator reserve power [p.u].
$z^s_{k,t}, u^s_{g,t}$	A binary variable for on /off status of lines and units, respectively.
$v^s_{g,t}, w^s_{g,t}$	Startup/shutdown binary variable for units.
$\Delta V^s_{b,t}, V_b$	Voltage changes and voltage of each bus [p.u].
$\Delta\delta_k(l)$	Phase angle difference of blocks.
$\delta^s_{k,t}$	Phase angle difference across transmission line k.
δ^+_k, δ^-_k	Non-negative variables used to replace $\delta^s_{k,t}$.
$f(t)$	The failure rate.
dl	Probability of CB failure.
$\lambda^s_{g,t}$	Dual variable.
N_k	Number of switching in line k.
RL	Reliability of CB
$EENS$	Expected Energy Not Supplied
$bj_{k,j}$	Binary variables for linearizing dl
uca, $uca1$	Binary variables.

C. Constants

R_g^{s+}, SR_g^{+}	Maximum ramp up/ramp down rate [p.u].
$P_g^{\max}, P_g^{\min}$	Active power limitation for generators [p.u].
$Q_g^{\max}, Q_g^{\min}$	Reactive power limitation for generators [p.u].
$PD_{b,t}^{s}$	Bus demands [p.u.].
$P_K^{\max}, Q_K^{\max}$	Active/reactive power limit for lines [p.u].
$\Delta V^{\max}, \Delta V^{\min}$	Voltage change limitation for buses [p.u].
$SU_{g,t}, SD_{g,t}$	Start-up and shut-down cost for generators [$].
$\delta_k^{\max}, \delta_k^{\min}$	Max/min of angle difference across line *k*.
$M, VOLL$	Large positive numbers (depends on the system under study).
dt	Time changes [h].
n_1	number of switching which is occurred before *t*.
P	Value of $f(t)$ for $N = 23$.
zc_k^s, uc_g^s	Contingency state of (line *k*) / (unit *g*).
Cj_j, lj_j	Coefficients for linearizing failure probability of CB at *j*.
τ	Time horizon.
UT_g, DT_g	Minimum down time and minimum up time for unit *g*.

I. INTRODUCTION

A. Background and Motivation

Nowadays, transmission networks that are more flexible and secure are more efficient. So, the power generating companies in the electricity market favor to invest more in such. Even some large consumers favor buying their load from such networks because they pay less.

In the electricity market, the independent system operator (ISO) encourages transmission companies (TRANSCO) to extend their smart grids. Complete control of transmission lines improves system reliability and improves the market congestion surplus. System operators can sustain better voltage stability, increase transmission capacity, enhance system reliability by switching some lines on the grid, and changing the network configuration.

Optimizing the network configuration is an accepted approach because can be achieved to a more controllable and more important efficiency network by optimally TS. Optimizing unit partnerships with optimal TS can lead to cost savings. Because with optimal TS, the network configuration is optimized and the transmission congestion is reduced.

This lets units to be synchronized with the network at a lower price. Full network control is not currently feasible for optimal network utilization. Nevertheless, an optimum TS at a low cost to the user can have a significant influence on network controllability.

Optimal TS or reactive power compensation devices such as capacitors and FACTS can better respond to load increases with the existing system. To increase the security and stability levels of the power system, it requires high controllability in the power system, which is also affected by various maneuvers in the power grids. The maneuverability of the network depends on the various characteristics of the network and its structure.

In this case, the utility of different maneuvers to determine the level of network controllability is important.

Therefore, the main indicators considered in the study of various maneuvering tools in the Fars power grid, in Iran, are determining the type and number of appropriate equipment, how to configure it to increase levels of network controllability, and static and dynamic security.

B. Goals

The purpose of this work is to investigate the utility of maneuvering in the Fars power grid to increase the controllability and security of the grid and to select appropriate methods along with the required equipment.

Since the problem of voltage stability is affected by the reactive power supply in the grid, it will be attempted to solve the problem of placing sufficient reactive power sources in the grid with the possibility of maneuvering the grid simultaneously.

To solve this problem, a problem of simultaneous optimization of reactive power sources with grid maneuverability is proposed, where the "VSM" (voltage security margin) index is considered. VSM is the amount of load on the grid that does not exceed the voltage range of the nodes as well as the grid current.

C. Related Works and Manuscript Organization

In reference [1], the distributed outputs such as wind generators are considered to provide balance to the power system. The use of FACTS devices such as SVC and STATCOM to keep voltage stability in the power system is also discussed in [2–4].

According with [2–4], FACTS by providing reactive power to the grid at optimum places, it makes the voltage to stabilize in the voltage stability range. In [5], the study of power-angular stability in a power system was discussed by implementing the proper performance of protecting equipment such as a breaker. In other words, by implementing proper maneuvers by the grid protection, the angular-power stability is kept.

In reference [6] has also leads to the use of distributed generation to develop grid voltage and decrease transmission line bottlenecks, followed by static security. Based on this research, the proper maneuvers by various elements such as protecting equipment, distributed products, and FACTS devices can enhance the stability and protection levels of the power system. Therefore, the utility of performing maneuvers in the Fars power grid increases the security and controllability of the Fars power grid.

The remaining work is structured as follows: Section II presents a proposed model for the problem-solving process. Section III contains the simulation results. Finally, Section IV is devoted to the conclusion.

II. Proposed Model

One method to enhance network loading is to enhance line capacity without having to establish a new line. Various ingredients can be used to enhance the capacity of the lines, such as TS and placing capacitors on buses.

With the entry and exit of the lines, the grid structure will transfer to decrease the congestion of the lines and make the generators less costly to use and decrease costs.

Nevertheless, since a large number of switches can decrease the key lifetime and enhance the likelihood of a failure, this paper introduces a novel model to diminish the number of switches and enhance network reliability. Eventually, a full network model is provided by TS and installing capacitors to enhance network loading.

A novel model using TS, regarding CB reliability as a restriction on limiting the number of switching and capacitor placement along with the VSM model will introduce.

The objective function of the problem in (1) comprises minimizing the production cost (C), the load-off cost, the capacitance replacement cost, and the cost correlated with a VSM. It is also assumed that production costs including reactive power and reserve are accessible.

The cost of generating power is assumed to be linear. These costs of setting up and shutting down the production units are multiplied by the binary variables, so raising the costs of setting up or shutting down the units. The cost of maintaining a CB and load-off costs are determined by C_r and C_l [7].

$$\min z^{down} = \sum_t \sum_g \begin{bmatrix} C(P^0_{g,t}) + SU_{g,t}(v^s_{g,t}) \\ +SD_{g,t}(\omega^s_{g,t}) + C\Delta r^s_{g,t} + C_r + C_l \end{bmatrix} + \sum_b C_c . uca1(b) - f(P_{Gi,u}, P_{Di}, Q_{Di}) \quad (1)$$

Limitations (2) and (3) are correlated with the active and reactive power limitations in which the occurrence of the unit event is g. limit (4) describes the binary logic of binary variables. Limitations (5) and (6) show the minimum turn-on and turn-off times. Ramp rate restraints are presented in (7) and (8).

The generator entry and exit limitations, the ramp-up and ramp-down limitations, and the reserve capacity limit of any generator are presented in (9).

In (10) is described the balance of active power concerning line losses also load offsets. In the equalization, in addition to normal conditions, the emergency conditions are involved. $\boldsymbol{\Delta r^s_{g,t}}$ is zero under normal conditions.

Equation (11) determines the reactive power balance limitation. $\boldsymbol{zc^s_k}$ is the emergency mode of the line K.

If the line is turned off, $\boldsymbol{z^s_{k,t}}$ will be zero and the power of transferring in the lines between a positive and a negative will be great. Limits (14) and (15) associate with the load flow limitations of the lines.

The active and reactive power limitations are shown in (16)–(19). gb_k and bg_k are the properties of lines and explained in [8]. In this load flow, varieties of the Buses voltage amplitude and Buses Voltage Angle limitations are considered in (20)–(24), respectively.

$$P_g^{\min} u^s_{g,t} uc^s_g \le P^0_{g,t} + \Delta r^s_{g,t} \le P_g^{\max} u^s_{g,t} uc^s_g \quad (2)$$

$$Q_g^{\min} u^s_{g,t} uc^s_g \le Q^s_{g,t} \le Q_g^{\max} u^s_{g,t} uc^s_g \quad (3)$$

$$v^s_{g,t} - \omega^s_{g,t} = u^s_{g,t} - u^s_{g,t-1} \quad (4)$$

$$\sum_{t'=t-UT_g+1}^{t} u^S_{g,t'} \le u^S_{g,t} \quad \forall g, t \in \{UT_g, ..., \tau\} \quad (5)$$

$$\sum_{t'=t-DT_g+1}^{t} \omega^S_{g,t'} \le 1 - u^S_{g,t} \quad \forall g, t \in \{DT_g, ..., \tau\} \quad (6)$$

$$P^0_{g,t} - P^0_{g,t-1} \le R_g^{s+} u^s_{g,t-1} + R_g^{SUs} v^s_{g,t} \quad (7)$$

$$P^0_{g,t-1} - P^0_{g,t} \le R_g^{s+} u^s_{g,t} + R_g^{SUs} \omega^s_{g,t} \quad (8)$$

$$-SR_g^+ \le \Delta r^s_{g,t} \le SR_g^+ \quad (9)$$

$$\sum_{\forall g(b)} \left(P^o_{g,t} + \Delta r^s_{g,t}\right) - \sum_{\forall k(b,m)} \left(P^s_{k,t} + 0.5PL^s_{k,t}\right) = PD^s_{b,t} - P^s_{sh_{b,t}} \quad (10)$$

$$\sum_{\forall g(b)} Q^s_{g,t} + \sum_{\forall k(b,m)} \left(Q^s_{k,t} - 0.5QL^s_{k,t}\right) = QD_{b,t} \quad (11)$$

$$P^s_{b,m,k,t} - M\left(1 - z^s_{k,t} zc^s_k\right) \le P^s_{k,t} \le P^s_{b,m,k,t} + M\left(1 - z^s_{k,t} zc^s_k\right) \quad (12)$$

$$Q^s_{b,m,k,t} - M\left(1 - z^s_{k,t} zc^s_k\right) \le Q^s_{k,t} \le Q^s_{b,m,k,t} + M\left(1 - z^s_{k,t} zc^s_k\right) \quad (13)$$

$$-P_k^{\max} z_{k,t}^{s} zc_k^s \le P_{k,t}^s \le P_k^{\max} z_{k,t}^{s} zc_k^s \quad (14)$$

$$-Q_k^{\max} z_{k,t}^{s} zc_k^s \le Q_{k,t}^s \le Q_k^{\max} z_{k,t}^{s} zc_k^s \quad (15)$$

$$\begin{aligned}&\left(gb_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^s(l) - M\left(1-z_{k,t}^s zc_k^s\right)\right) \le PL_{k,t}^s \\ &\le \left(gb_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^s(l) + M\left(1-z_{k,t}^s zc_k^s\right)\right)\end{aligned} \quad (16)$$

$$0 \le PL_{k,t}^s \le z_{k,t}^s . zc_k^s . gb_k \left(\delta_k^{\max}\right)^2 \quad (17)$$

$$\begin{aligned}&\left(-bg_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^s(l) - M\left(1-z_{k,t}^s zc_k^s\right)\right) \le QL_{k,t}^s \\ &\le \left(-bg_k \sum_{l=1}^{L} k(l)\Delta\delta_{k,t}^s(l) + M\left(1-z_{k,t}^s zc_k^s\right)\right)\end{aligned} \quad (18)$$

$$0 \le QL_{k,t}^s \le -z_{k,t}^s . zc_k^s\, bg_k \left(\delta_k^{\max}\right)^2 \quad (19)$$

$$-S_k^{\min} \le \delta_{k,t}^s \le S_k^{\max} \quad (20)$$

$$\Delta V^{\min} \le \Delta V_{b,t}^s \le \Delta V^{\max} \quad (21)$$

$$\begin{aligned}&\left(-\Delta SP_k^{\max} - M\left(z_{k,t-1}^s - z_{k,t}^s + 1\right) zc_k^s\right) \le \delta_{k,t}^s \\ &\le \left(\Delta SP_k^{\max} + M\left(z_{k,t-1}^s - z_{k,t}^s + 1\right) zc_k^s\right)\end{aligned} \quad (22)$$

$$\delta_{k,t}^{+a} - \delta_{k,t}^{-a} = \delta_{k,t}^s \quad (23)$$

$$\Delta V_{b,t}^{+a} - \Delta V_{b,t}^{-a} = \Delta V_{b,t}^s \quad (24)$$

The capacitance constraints are as follows:

$$Q_{c1}(s,b,t) \le Q_c uca(s,b,t) \quad (25)$$

$$\begin{aligned}sd_1(s,b,t) &= \frac{V^2(s,b,t)}{x_c} = \frac{\left(1+\Delta V(s,b,t)\right)^2}{x_c} \\ &= \frac{1+2\Delta V(s,b,t)+\Delta V^2(s,b,t)}{x_c} = \frac{1+2\Delta V(s,b,t)}{x_c}\end{aligned} \quad (26)$$

$$Q_{c1}(s,b,t) \ge -uca(s,b,t)M \quad (27)$$

$$Q_{c1}(s,b,t) \le uca(s,b,t)M \quad (28)$$

$$Q_{c1}(s,b,t) \ge \left(sd_1(s,b,t) - \left(1-uca(s,b,t)M\right)\right) \quad (29)$$

$$Q_{c1}(s,b,t) \le \left(sd_1(s,b,t) + \left(1-uca(s,b,t)M\right)\right) \quad (30)$$

$$n_c = \sum_b uca1(b) \quad (31)$$

The VSM constraints are as follows:

$$PD'_{b,t} = (1+\lambda).PD_{b,t} \quad (32)$$

$$QD'_{b,t} = (1+\lambda).QD_{b,t} \quad (33)$$

$$P'_{g,t} = \left(1+\lambda+K_G\right).P_{g,t} \quad (34)$$

Reference [9] has introduced a security outline of CB subjected to random shocks. Random shocks use for failure modeling in various sources and various elements of the power system [10–12].

$$f(t) = 0.002N^2 + 40.43N \quad (35)$$

when a t hour period is considered, N is the number of switching which has happened during period t. that is added up by the number of switching which has happened in previous periods.

To put it more clearly, N is a combination of two various parts. The previous is the variable amount of switching in period t. The end is the sum of each switching before t and is fixed, which is thought that if a CB gives its most expected (maximum) amount of switching, that will not function anymore. $f(t)$ is an innovative measure. It has no units or dimensions. This function is distributed by the highest rate that $f(t)$ can make (P) to give us a contingency for CB failure.

$$dl = \frac{0.002N^2 + 40.43N}{P} \quad (36)$$

In (36), the numerator expresses CB failure. This is based on the number of switching N also the denominator is CB failure, $f(t)$, if N leads to its maximum.

This implies that P is the maximum amount that $f(t)$can use (i.e. if CB is in the most critical condition) also CB will fail to perform next that. dl is the likelihood of CB failure in a t-hour period. As by higher (lower) likelihood of CB failure, the reliability of CB reductions (raises), the following equation is:

$$RL = 1 - dl \quad (37)$$

RL describes the reliability of CB. One idea of this paper is to develop the reliability of CB and the network, by mitigating the number of switching. This goal will be met while dl is nearest to zero.

The expected energy not supplied (EENS) limitations define with regarding the likelihood of CB failure according to Equations (38) – (42):

$$EENS = \frac{1}{P}\Big(\sum_{k}\sum_{j} 0.002 Pc_{k,j} + \sum_{k}\sum_{j}(40.43+0.004n_1)Pj_{k,j} + \sum_{b}\sum_{t}\left(n^2{}_1+40.43n_1\right)P_{sh_{b,t}}\Big) \quad (38)$$

$$-bj_{k,j}M \le Pc_{k,j} \le bj_{k,j}M \quad (39)$$

$$P_{sh_{b,t}}Cj_j - \left(1-bj_{k,j}\right)M \le Pc_{k,j} \le P_{sh_{b,t}}Cj_j + \left(1-bj_{k,j}\right)M \quad (40)$$

$$-bj_{k,j}M \le Pj_{k,j} \le bj_{k,j}M \quad (41)$$

$$P_{sh_{b,t}}lj_j - \left(1-bj_{k,j}\right)M \le Pj_{k,j} \le P_{sh_{b,t}} + \left(1-bj_{k,j}\right)M \quad (42)$$

In (38), $Pj_{k,j}$ and $Pc_{k,j}$ are the part of load shedding, begun by line interruption. $Pj_{k,j}$ is the multiplication of $bj_{k,j}$, $P_{sh_{b,t}}$ and lj_j. $Pc_{k,j}$ is the multiplication of $bj_{k,j}$, $P_{sh_{b,t}}$ and Cj_j. EENS and EENS costs are determined based on the failure probability of CB.

$$C_r = VOLL \times EENS \quad (43)$$

In (43), C_r is the EENS cost and *VOLL* is a great positive number. Because any CB has its repair and maintenance cost, the cost should add up to this operation costs.

$$C_l = dl \times C_e \quad (44)$$

In (44), C_e is the cost of repair and maintenance of CB. In this instance, if the number of switching reduces, dl and C_l will be reduced correspondingly, and finally the operation cost will be reduced.

III. Simulation Results

The proposed model has been implemented using GAMS optimization software on the Fars province 93-bus network as shown in Fig 1. The accuracy of the results indicates the validity of this proposed model.

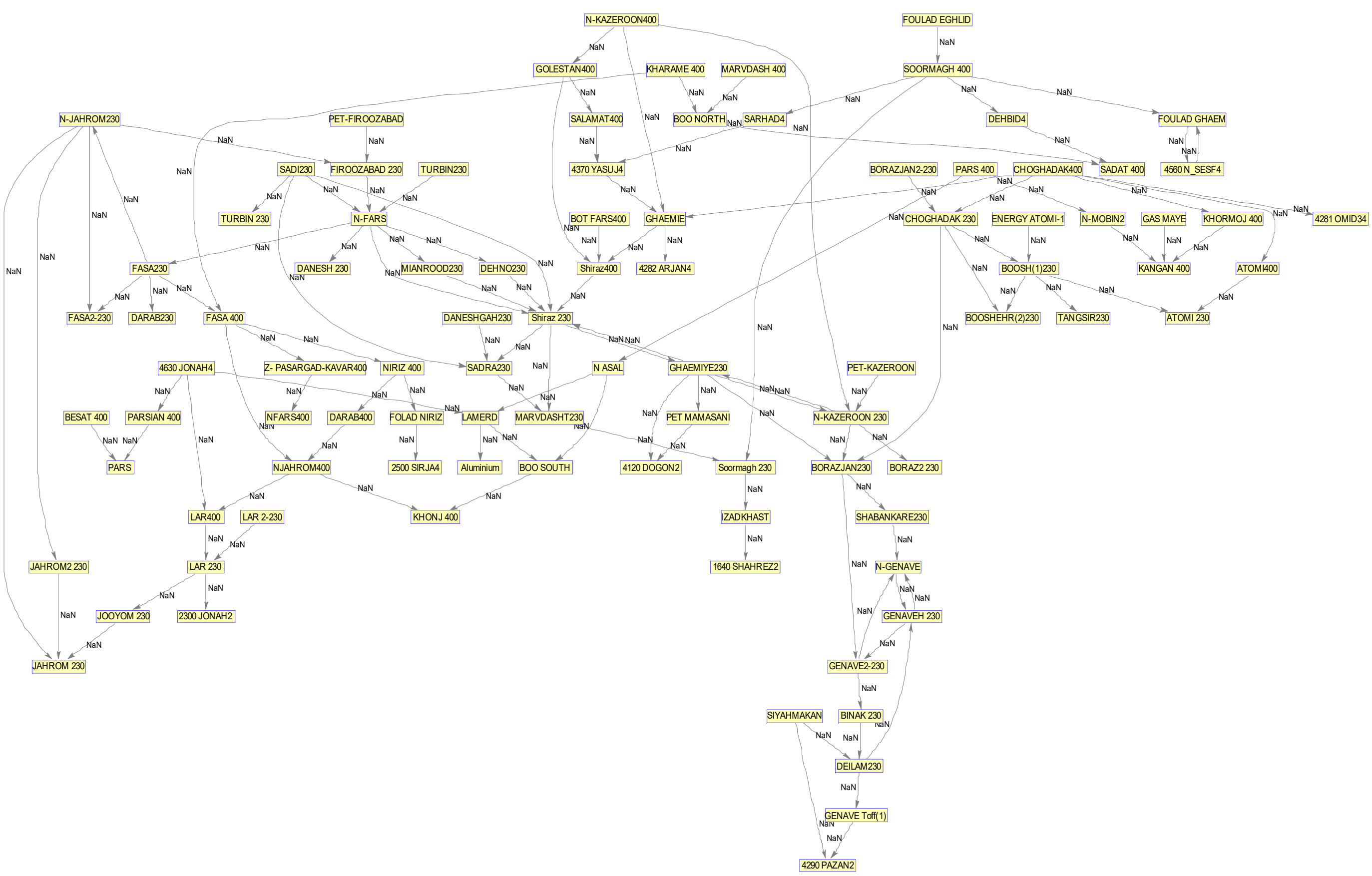

Fig. 1. View of Fars Transmission Network

A. Transmission Switching Results

In the non-switching mode (normal mode) there is naturally no change in the mode of entry and exit of the lines, which means that the switching maneuver is not performed.

In the first three lines of the results listed in Table I, the rate of change of modes for the three-line input and output over 24 hours is shown, which can be recommended to reduce the number of switches to achieve the desired response by implementing the proposed method as a result.

In the second part of Table I the other characteristics are stated. It should be noted that the total cost stated in Table I is the cost of operating the network.

Because transmission switching causes a cheaper production source to generate more power, resulting in reduced congestion and lower total operating costs. It also reduces maintenance costs by reducing the number of switches, thus reducing the total cost that is the purpose of the proposed method.

B. Capacitor Placement Results

The optimal placement of the capacitors to achieve the optimal objectives of the problem is included 35, 70, 80, 83, 85, 89, and 92 buses.

Once the capacitor has been selected, the time that capacitors enter and exit are important, which can set the voltage of the grid to the desired range. the time that capacitors enter and exit for the desired voltage status of all buses are shown in Fig. 2.

For example, the bus voltage is first recorded at 2:00 pm without capacitors (as shown in Fig. 1). It is also observed that the voltage of some buses has reached about 0.95 p.u.

According to Fig. 2 at 2:00 pm all the capacitors are connected to the grid except the capacitor which is 85 for the bus. a look back at Fig. 3 shows that at 2:00 pm the bus voltage of 85 is about 1 p.u indicating that this capacitor should not be in the network at 2:00 pm.

Capacitating at 2.00 pm not only adjusts the voltage of those buses and improves the power factor of the same region but also develops the level of voltage of the buses connected to that region. This problem is illustrated in Fig. 4.

TABLE I. RESULTS OF IMPLEMENTING THE PROPOSED METHOD ON THE REAL NETWORK

	Time/Line	Number of TS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Without TS	30	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	108	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	113	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
With Ts	30	9	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
	108	9	0	0	0	1	1	1	0	0	0	1	0	0	0	0	1	1	1	0	0	0	1	0	1	1
	113	7	1	1	1	0	0	1	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	1	0
Proposed Model	30	7	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0
	108	6	0	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0
	113	5	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1

	Line	Number of TS	Probability of failure (1/24h)	Reliability (1/24h)	Maintenance Costs ($/24h)	EENS (MWh)	Total Costs($)
Without TS	30	-	-	-	-	0	1.8249×10^7
	108	-	-	-	-		
	113	-	-	-	-		
Without TS	30	9	0.01213	0.9878	12.13	50.32	1.7825×10^7
	108	9	0.01213	0.9878	12.13		
	113	7	0.00943	0.9905	9.43		
Proposed Model	30	7	0.00943	0.9905	9.43	25.462	1.7098×10^7
	108	6	0.0080	0.992	8		
	113	5	0.0067	0.9933	6.7		

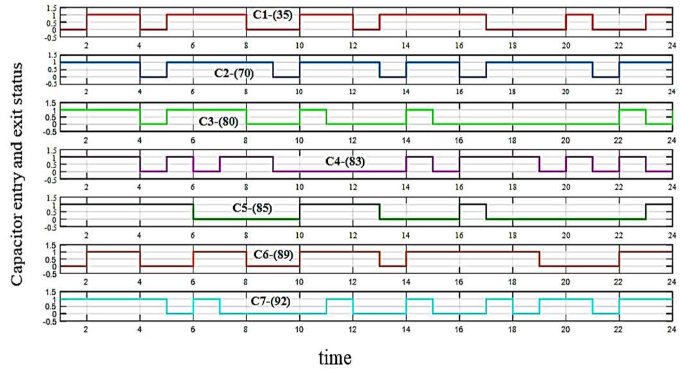

Fig. 2. The time that capacitors enter and exit.

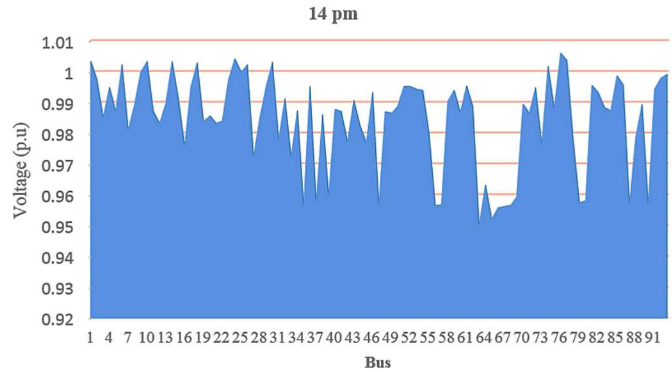

Fig. 3. Bus voltage without capacitors

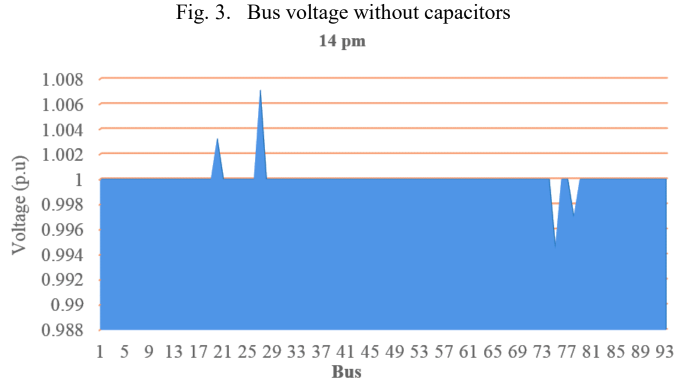

Fig. 4. Bus voltage with capacitors

C. Influence of Transmission Switching and Capacitor Placement on Voltage Security Margin

Fig. 5 shows a comparison of VSM curves for the proposed method and the normal model. The first point to note is the rise of the secure margin starting point from 0.985 p.u to about 1 p.u.

It should be noted that the reduction of the bus voltage variations is due to the transmission switching and capacitor placement, which makes the proposed method curve slope slower. This causes the VSM of the grid to increase, taking into account the permissible voltage limit, and as shown in Fig. 5, the value of λ for the proposed method is 0.3, indicating an increase in system load. Hence, if it does not consider the permissible voltage constraints, system collapse is considerably more likely to occur at higher loads, so the operator needs to consider the flexibility of the system against loading for operational calculations.

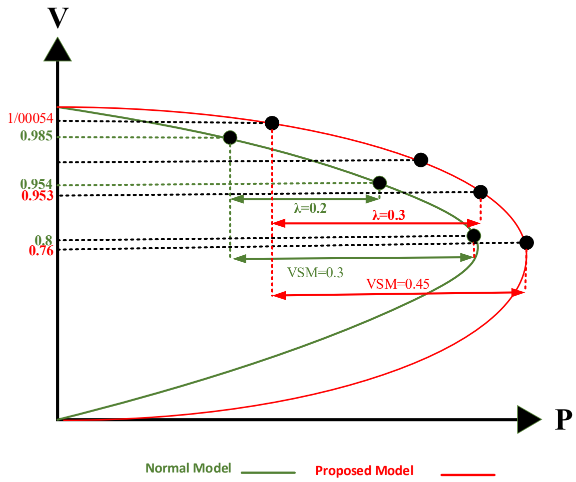

Fig. 5. Comparison of VSM curves

IV. Conclusion

This paper addressed the voltage security constrained optimal power flow considering smart transmission switching maneuvers. Overall, the results showed that the implementation of the proposed method in both economic and technical aspects can help optimize the utilization of the transmission network. From the economic perspective, it is expected to reduce the cost of operating the transmission network by implementing this method, while with switching control the average amount of energy not supplied is not high. Technically, the proposed method is expected to help increase system reliability against load changes and increase network maneuverability.

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